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TIGGERC—Turbomachinery Interactive Grid Generator for 2-D Grid Applications and Users Guide

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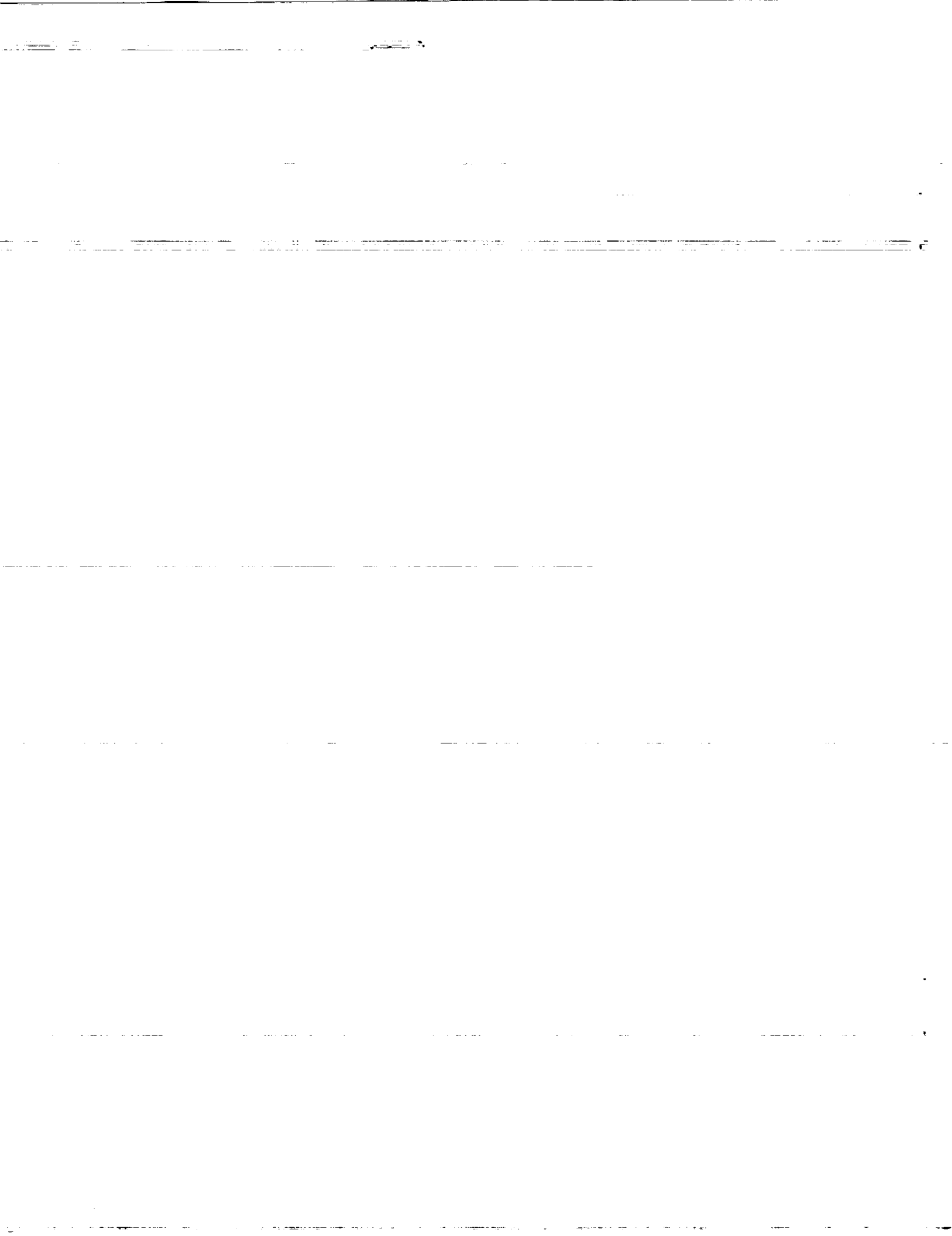
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For 2-D Grid Applications
And Users Guide**

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Nomenclature

A	Square root of the ratio of end spacings
B	1 over the square root of the end spacings multiplied
$B_{i,n}(u)$	Bernstein polynomial
$C(n, i)$	Binomial coefficient
$f_i(u)$	Blending functions
J	Jacobian
$L_j(\lambda)$	Linear Term
m'	Non-dimensional meridional distance
P	Forcing function for Possion's equation
P_1	Damping factor
P_2	Damping factor
$p(u)$	Parametric function
Q	Forcing function for Possion's equation
$r(\xi, \eta)$	General form for transfinite interpolation
r_u	Cell spacing ratio at the upper portion of the curve
r_l	Cell spacing ratio at the lower portion of the curve
r	Radius
S	Normalized arc length of a curve
$S_j(\lambda)$	Damped cubic spline
S_u	Upper half of the normalized arc length of a curve
S_l	Lower half of the normalized arc length of a curve
$s(\xi)$	Arc length distribution for the hyperbolic tangent
Δs_1	Spacing at the beginning of the arc
Δs_2	Spacing at the end of the arc
Δs_u	Spacing at the upper half of the arc
Δs_l	Spacing at the lower half of the arc
x	Rectilinear coordinate in the x - direction
y	Rectilinear coordinate in the y - direction
z	Distance along the turbomachine axis

Nomenclature

$\alpha_j(\lambda)$	Cubic term
$\beta_j(\lambda)$	Cubic term
δ	Delta function in the hyperbolic tangent distribution
η	Normal direction used for the transfinite interpolation
$\eta(x, y)$	Completes the mapping from physical to computation space
θ	Angular distance
λ	Independent variable
$\mu(\xi)$	The hyperbolic tangent function
ξ	Points distributed along the arc length S
ξ	Parallel direction used for the transfinite interpolation
$\xi(x, y)$	Conversion from physical to computational space
ϕ_n	Blending function
ψ_m	Blending function

Definition of Buttons

BS	Backspace Key
DA	Down Arrow
ESC	Escape Key
LM	Left Mouse Button
MM	Middle Mouse Button
M	M Key
RM	Right Mouse Button
TAB	Tab Key
UA	Up Arrow

Summary

A two-dimensional multi-block grid generator has been developed for a new design and analysis system for studying multiple blade-row turbomachinery problems. TIGGERC is a mouse driven, interactive grid generation program which can be used to modify boundary coordinates and grid packing and generates surface grids using a hyperbolic tangent or algebraic distribution of grid points on the block boundaries. The interior points of each block grid are distributed using a transfinite interpolation approach. TIGGERC can generate a blocked axisymmetric H-grid, C-grid, I-grid or O-grid for studying turbomachinery flow problems. TIGGERC was developed for operation on Silicon Graphics workstations. Detailed discussion of the grid generation methodology, menu options, operational features and sample grid geometries are presented.

1.0 Introduction

Computation of flows through multi-blade-row turbomachinery problems with Navier-Stokes flow solvers has become more prevalent in recent years[1-5]. These solvers and problems require carefully crafted meshes. More recently, interactive grid generation has made itself known for different types of applications in the aerospace field, especially, in turbomachinery[6-7]. The importance of creating a mesh quickly and efficiently plus being able to modify the mesh interactively can provide substantial productivity gains in analyzing and designing turbomachinery for advanced aircraft engine applications.

TIGGERC is an interactive mouse driven grid generation program which can be used to create mixed H-, C-, O- and I-grid meshes for studying any two-dimensional flow problem. This pertains to external as well as internal flow problems. The code was written for

turbomachinery applications, but, it is useful for any general geometry flow problem in 2-D. The code was written in a multi-block fashion to provide flexibility to the grid generation.

Grid generation has generally been a batch mode operation with little if any interaction by the user to obtain a smooth grid with user specified distribution of points for accurate CFD computations. TIGGERC has several features which allow the user to modify the distribution of points in the grid and to obtain a smooth distribution along boundaries, therefore providing greater control on the grid generation as well as freedom for the user to define the grid as they choose.

1.1 Methodology

The initial operation of TIGGERC is to create or read geometry for any two-dimensional problem. The code was primarily written for axisymmetric turbomachinery problems, however, the geometry can be specified in any general 2-D coordinate system. The generation of geometry, i.e. flowpath coordinates, can be created manually or input from a data file, (see Appendix A). The code is written in a modular fashion, primarily in FORTRAN, but with C routines for faster graphics. The user interface is built with the Forms Library[8] routines. The coordinates for the grid can be input in several forms, for example, cylindrical (r - z), rectilinear (x - y) or non-dimensional (m' - θ). Once the 2-D boundaries have been established, a grid can quickly be generated for any 2-D flow solver. TIGGERC outputs a grid file in plot3d multigrid format[9].

As mentioned above, TIGGERC is a multiple block grid generator. To illustrate this, Figure 1 shows how the blocks and rows of blocks are formed to set the boundaries upon which the grid will be generated. The input coordinates representing each block are input as individual blocks starting from the first row, first block, to

the last row, last block. As shown in Figure 1, the first block will have a inlet, exit, upper and lower boundary. Each block in each row is defined this way until the entire domain has been specified. The domain can be made to flow in any direction, the grid can be generated for many types of flow problems including radial.

1.1.1 Grid Generation Techniques

With the flow domain specified by the block boundaries, the grid is generated by distributing points on the boundaries of the block and then using a transfinite interpolation method to distribute the points in the interior of the block. First, the grid is stretched along the boundaries. The nomenclature of stretching can be described as though the curve were a spring and the points represent the amount of stretch in the spring. For example, if the grid was tightly packed at one end of the curve the spring would be coiled more at one end and stretched out toward the other end. This is what is meant by stretching. There are two types of stretching implemented in TIGGERC: hyperbolic tangent and geometric (often referred to as algebraic).

The code defaults to the hyperbolic tangent stretching function. Thompson, Warsi and Mastin [10] have given detailed information as to the methodology used to obtain the distribution. The distribution can be implemented as follows for spacings specified at both ends. Let there be an arc length, S , varying from 0 to 1 as ξ varies from 0 to 1: $S(0)=0$, $S(1)=1$. Also, spacings are specified at $\xi=0$ and $\xi=1$: $S(0) = \Delta s_1$, $S(1) = \Delta s_2$. The hyperbolic tangent stretching is as follows.

$$A = \sqrt{\frac{\Delta s_2}{\Delta s_1}} \quad (1)$$

$$B = \frac{1}{\sqrt{\Delta s_1 \Delta s_2}} \quad (2)$$

then the following is solved for δ :

$$\frac{\sinh \delta}{\delta} = B \quad (3)$$

The arc length distribution is given by

$$s(\xi) = \frac{\mu(\xi)}{A + (1-A)\mu(\xi)} \quad (4)$$

where

$$\mu(\xi) = \frac{1}{2} \left\{ 1 + \frac{\tanh \left[\delta \left(\xi - \frac{1}{2} \right) \right]}{\tanh \left(\frac{\delta}{2} \right)} \right\} \quad (5)$$

Thus from the above definitions, the distribution of points can be obtained along any curve S . This methodology was incorporated into the specification of points along the block boundaries.

The other function which was used to geometrically stretch the grid or sometimes referred to as an algebraic stretched grid is described below. The grid can be distributed as a polynomial function [10]. Assuming an arc length S , the total length can be divided in half such that

$$S = S_u + S_l \quad (6)$$

where

$$S_u = \Delta s_u \sum_{n=0}^{nu-1} r_u^n \quad (7)$$

and

$$S_l = \Delta s_l \sum_{n=0}^{nl-1} r_l^n \quad (8)$$

The geometric spacing on the arc can be determined as a function of the stretching ratio for the upper half of the arc r_u and the lower half of the arc r_l . Therefore, in order to match the two ends of the total length of arc, the ends must meet at

$$\Delta s_l r_l^{n_l-1} = \Delta s_u r_u^{n_u-1} \quad (9)$$

Thus, there are two equations and four unknowns. The user could supply either the stretching factors, r_u and r_l or the first spacing at the end of the boundaries Δs_u and Δs_l . Only the geometric ratio, r , can be input to TIGGERC; the code computes Δs_u and Δs_l internally (two equations and two unknowns). Then, from equations (6) and (9) the spacing along the arc can be obtained which specifies the grid geometrically.

There are other grid stretching functions which could have been incorporated into the code, but for simplicity of operation, the two functions above have been extensively used for turbomachinery problems and were easiest to implement. The default stretching can be changed by the user in the setup menu. The procedure to modify the stretching will be discussed later in this report.

1.1.2 Transfinite Interpolation

Once the boundary points have been distributed, the grid has to be generated in the interior space of the block. This can be done in several different ways and after some consideration in the various grid generation procedures. The transfinite interpolation[10] method was chosen as the primary procedure to compute the interior points. This is essentially a two directional linear Lagrange interpolation in each curvilinear direction. The interpolation is "transfinite" since it matches the function on the entire boundary defined by $\xi = 0$ and $\xi = 1$ and by $\eta = 0$ and $\eta = 1$. With the use of the blending functions ψ and ϕ , the general form of the transfinite interpolation becomes

$$\begin{aligned} r(\xi, \eta) = & \sum_{n=1}^N \phi_n(\xi) r(\xi_n, \eta) \\ & + \sum_{m=1}^M \psi_m(\eta) r(\xi, \eta_m) \\ & - \sum_{n=1}^N \sum_{m=1}^M \phi_n(\xi) \psi_m(\eta) r(\xi_n, \eta_m) \end{aligned} \quad (10)$$

equation (10) can be written as

$$\begin{aligned} r(\xi, \eta) = & \sum_{m=1}^M \psi_m(\eta) r(\xi, \eta_m) \\ & + \sum_{n=1}^N \phi_n(\xi) [r(\xi_n, \eta) \\ & - \sum_{m=1}^M \psi_m(\eta) r(\xi_n, \eta_m)] \end{aligned} \quad (11)$$

The two-directional transfinite interpolation can thus be implemented in two unidirectional interpolation steps by first performing the unidirectional interpolation in one direction, η , over the entire field and then interpolating in the discrepancy on the $\xi = \xi_n$ lines over the entire field in the other direction.

1.1.3 Damped Cubic Spline

The spline function used in TIGGERC is a damped cubic spline. To represent input data as accurately as possible it was desirable to use damped cubic spline routine which could also be made to emulate a pure cubic spline if the correct parameters are specified for the spline. The spline procedure, developed by K. D. Lee and J. M. Loellbach [11,12,13], may be constructed from a linear term and two cubic terms multiplied by damping factors between any two data points. Let the spline S , with independent variable λ be,

$$S_j(\lambda) = L_j(\lambda) + P_1 \alpha_j(\lambda) + P_2 \beta_j(\lambda) \quad (12)$$

$$0 \leq \lambda \leq 1 \quad (13)$$

where L_j is the linear term, α_j and β_j are the cubics with P_1 and P_2 the damping factors. The damping factors have been preset at the beginning of the program to a highly damped value, however, the damping can be reduced to increase curvature between original points. Typical damping values can range from 0 to 10. Some experimentation will be required to obtain the desired damping. This spline routine is also used to parametrically specify the grid along the boundaries. If an undamped boundary grid is desired, the damping factors will have to be modified for the grid as well. If the default values are retained the new curve will represent the old fairly accurately. Again some experimentation will be necessary to obtain a different damping from the default. The default damping will in general give nicely damped curves which represent the input data points fairly precisely and in practice these parameters don't normally need modification unless a true cubic spline is desired.

1.1.4 Bezier Curves

One feature frequently used in TIGGERC is the Bezier Curve[14] function to modify boundaries. Curve-defining techniques interpolate a given set of points, an alternative approach to this would be a curve which only approximates given points. Interpolation routines have their disadvantages in CAD programs. An easier method would be to control the curve shape in a more predictable way by changing a few parameters. Bezier's curve does this quite well. Bezier started with the principle that any point on a curve segment must be given by a parametric function of the following form:

$$p(u) = \sum_{i=0}^n p_i f_i(u) \quad u \in [0, 1] \quad (14)$$

where p_i vectors are represented by $n + 1$ vertices of a characteristic polygon. These vertices are called the control points and $f_i(u)$ are the blending functions required to satisfy the properties.

Bezier required the following:

1. The curve segments must start on p_0 and end on p_n .
2. The tangent at p_0 must be given by $p_1 - p_0$ and the tangent at p_n by $p_n - p_{n-1}$.
3. In general, the r th derivative at the end point must be determined by its r neighboring vertices. This allows virtually unlimited control of the continuity at the joints between curve segments of a composite Bezier curve.
4. The functions $f_i(u)$ must be symmetric with respect to u and $(1 - u)$. This means that we can reverse the sequence of vertex points defining the curve without changing the shape of the curve.

Bezier chose the Bernstein polynomials to satisfy these conditions. It turns out the functions Bezier selected depends on the number of vertices used to specify a particular curve. Thus, equation (14) becomes

$$p(u) = \sum_{i=0}^n p_i B_{i,n}(u) \quad (15)$$

where

$$B_{i,n}(u) = C(n, i) u^i (1 - u)^{n-i} \quad (16)$$

and where $C(n, i)$ is the binomial coefficient

$$C(n, i) = \frac{n!}{i! (n-i)!} \quad (17)$$

When i and $u = 0$, $u^i = 1$; also $0! = 1$. Observe that for $(n + 1)$ vertices, $B_{i,n}(u)$ yields an n th-degree polynomial. Expanding equation (15) yields for 4 control points

$$p(u) = (1 - u)^3 p_0 + 3u(1 - u)^2 p_1 + 3u^2(1 - u) p_2 + u^3 p_3 \quad (18)$$

TIGGERC has implemented the 4 control point Bezier curve for flowpath and station editing capabilities (two end points and two adjustable control points).

1.1.5 Elliptical Smoothing

Elliptical smoothing has been included in the code as another feature sometimes used in grid generation. The elliptical smoother was adapted from Sorenson[15] and applied to each block. The smoother was designed such that the grid is computed orthogonal to the upper and lower boundaries. The theoretical development of the system of equations can be denoted as the following. Let $\xi = \xi(x,y)$ and $\eta = \eta(x,y)$, which specifies the mapping from physical space to computational space. Thus, the mapping functions are required to satisfy Poisson equations

$$\xi_{xx} + \xi_{yy} = P \quad (19)$$

$$\eta_{xx} + \eta_{yy} = Q \quad (20)$$

The following relations are useful in transforming equations from physical and computational domains.

$$\xi_x = y_\eta / J \quad (21)$$

$$\xi_y = -x_\eta / J \quad (22)$$

$$\eta_x = -y_\xi / J \quad (23)$$

$$\eta_y = x_\xi / J \quad (24)$$

$$J = x_\xi y_\eta - x_\eta y_\xi \quad (25)$$

applying the above to (19) and (20) yields

$$\alpha x_{\xi\xi} - 2\beta x_{\xi\eta} + \gamma x_{\eta\eta} = -J^2 (Px_\xi + Qx_\eta) \quad (26)$$

$$\alpha y_{\xi\xi} - 2\beta y_{\xi\eta} + \gamma y_{\eta\eta} = -J^2 (Py_\xi + Qy_\eta) \quad (27)$$

where

$$\alpha = x_\eta^2 + y_\eta^2 \quad (28)$$

$$\beta = x_\xi x_\eta + y_\xi y_\eta \quad (29)$$

$$\gamma = x_\xi^2 + y_\xi^2 \quad (30)$$

Thus, solving (21), (22), (23), (24), and (25) for a particular choice of P and Q , and for a particular boundary condition creates the smoothed grid. The forcing functions P and Q are defined as

$$P(\xi, \eta) = P(\xi) e^{-a\eta} + r(\xi) e^{-c(\eta_{max} - \eta)} \quad (31)$$

$$Q(\xi, \eta) = Q(\xi) e^{-b\eta} + s(\xi) e^{-d(\eta_{max} - \eta)} \quad (32)$$

where a , b , c , and d are positive constants. The constraints applied to solve for the grid are the geometric spacing next to the wall and the angle of intersection between the body and the $\xi = \text{constant}$ line. The elliptical smoother as described above is implemented with the exception that the smoother does not create a normalized grid on the end boundaries of each block, only the upper and lower boundaries which tend to be flowpath geometries in turbomachinery problems.

The previous sections described the methodologies used to generate the grids. The following is a users guide to help locate the necessary tool kits for block modifications and grid generation.

2.0 USERS GUIDE

To start the program from the keyboard, enter **tigerc** (small letters). The program will display a title (Figure 2a) and then the main menu (Figure 2b). From the main menu, the user can access features to manipulate the boundary data, provide editing capabilities, write output files and generate the grid. The options include the Start menu to read the data from an input file or allows the geometry to be generated manually for

the gridding. The *Block Menu* selection to change the number of points, stretching and generate the grid block-by-block. The *Flowpath and Station Menu* options are used to manipulate upper, lower, inlet and end boundaries of each block. The *Edit Tools* option can be used to add blocks, delete blocks, and scale the geometry. The *Edit Tools* submenu also includes a parameter setup button used to modify titles, spline parameters, display plot values, max bezier/spline points, and block grid parameters, i.e. stretching. The *Write Output Files* option writes the restart file and grid file for a flow solver. The *Zoom/Translate* button is used to perform necessary zooming and translation of the graphics display. Finally, the *Quit* button terminates execution of the code. The following discussion will describe each menu operation and details of the functionality of each button. The order of discussion will begin with reading data into the grid generator followed by the various tool kits associated with block boundary manipulation and finally the grid generation itself. To simplify the operations, (RM) refers to the **right** mouse button push, (MM) refers to the **middle** mouse button push and (LM) refers to the **left** mouse button push. **WARNING:** The Forms Interface uses the **TAB** key to save input changes. **ENTER** key will return the operation unchanged.

2.1 TIGGERC: START

Once the main menu appears, place the mouse cursor over the *Start* button and hold down the **right** mouse button (RM). A pull down menu appears, drag the mouse over the selection desired and release. If the 2D-file option is selected, the code produces a file selector which defaults to the current directory and "*.inp" for the input file name. There is the option to change directories and default file name descriptor. The file can then be selected with the mouse or typed in manually. When the correct file has been identified, select the ready button. The initial plot

of the point data representing the blocks will appear. It is also possible to start TIGGERC with the file name specified. At the shell prompt, enter the following: "tiggerc -2d filename".

The other starting option, 2-D Scratch, is used to generate the blocks manually. The number of rows (in split flowpaths) and blocks (axial splits; for example blade leading edges and trailing edges) must first be specified to indicate how many total blocks are to be generated. Then for each boundary (upper, lower, inlet, exit) the code loops through the blocks requesting input coordinates.

2.2 TIGGERC: Block Menu

Once the block data has been read into the code, input by hand or modified with the editing tools, the next step is to generate a grid. This is done by selecting the *Block Menu* item on the main menu. The grid is automatically generated and displayed graphically. The main menu is replaced on screen by the *Block Menu*. The *Block Menu* has options listed which allow the user to modify the grid block by block (see Figure 3).

2.2.1 TIGGERC: Block Menu: Block Grid Mod

This option pertains to block grid modification and allows the grid to be modified in the normal direction applied to a specific block. This feature will allow modification of the number of points in the block plus the upper and lower boundary stretching. Select the *Block Grid Mod* button with the left mouse (LM) and the block menu will disappear. The code then waits until the block is selected. Placing the mouse over the desired block and pushing the left mouse (LM), the block will become highlighted in blue (Figure 4), and a new slider will appear in the upper right hand corner (Figure 5).

If the default hyperbolic tangent stretching has been set, the default values on the slider indicate the end point deltas. They are dimensional values set to the grid dimensions, for example, if the geometry of the grid is in inches as in the example shown, the deltas are in inches. To modify the normal spacing (axial) at the (front or back/ upper or lower) corners of the block, place the mouse in the slider on the particular delta that needs to be modified. For example, the upper delta on the front of the block. The number can be deleted by using the *Backspace* key (BS) or by typing the *Escape* button (ESC) which will cause the entire number in the box to disappear. Enter the new end point spacing and type the *TAB* button (TAB) which will save the delta and automatically generate a new grid for the block. Try modification of the upper delta on the back portion of the block and so forth. A sequence of modifications are shown in Figures 6a-6d.

The slider can change the number of points distributed along the block in the flow direction. To add or remove points in the block the mouse is placed over the slider and with the left mouse (LM) dragged as the new value is displayed in the box overhead. The new grid is automatically generated every time the left mouse button (LM) is released. The number of grid points can also be input in the box by clicking the mouse on the box over the slider and use the *Backspace* Key (BS) or *Escape* button (ESC). The number disappears waiting for a new number to be input. After typing in the new number of grid points desired, (TAB) and the new grid will be generated. A useful feature of the code is that the end point deltas will be automatically modified when the deltas are inconsistent with number of points desired (hyperbolic tangent stretch only). Figures 7a-7b show different grids with different point distributions.

If geometric stretching is specified to generate the grid, a stretching ratio is specified at each end instead of a delta. This might provide

greater flexibility than hyperbolic tangent stretch because the ratio of cell to cell spacing remains fixed for the number of points desired. The disadvantage is that the spacing at the end points cannot be specified.

Once the modification of the block has been completed, select the *Done* button which will save the new block information. There is no *Undo* button for this slider, to *Undo*, you must re-input the original number of points, deltas and/or stretching factors.

2.2.2 TIGGERC: Block Menu: Span Grid Mod

This pertains to spanwise grid modification and allows the grid to be modified in the parallel direction applied to a specific block. This feature will allow modification as to the number of points in the block plus the top and bottom boundary stretching. Select the *Span Grid Mod* button with the mouse and the block menu will disappear. The code then waits while the user selects the row of interest with the left mouse button (LM). Placing the mouse over the desired block and push the left mouse (LM), the entire block will become highlighted in blue (Figure 8), and again a slider will appear in the upper right hand corner.

Again, the features of this menu operate exactly like those describe in 2.2.1, except that they are applied to the grid in the flow direction as opposed to the normal direction. A sequence of modifications for the spanwise modifications are shown in Figures 9a-9d.

2.2.3 TIGGERC: Block Menu: Plot Grid

The *Plot Grid* option allows viewing the grid, grid and block boundaries together or the block boundaries by themselves. With the right mouse button (RM) held down over the option, the user can toggle between: Plot Block Boundaries, Plot Grid, or Plot Both. If the left mouse button (LM) is used, these same options will rotate. This

provides various views of the grid and geometry together. The rest of the options pertain to the block grid modifications available to the user.

2.2.4 TIGGERC: Block Menu: Elliptical

To apply the elliptical smoother to a block, select the *Elliptical* button from the menu. The mouse cursor is placed on the block desired to be smoothed and with the left mouse button (LM) selected. The block will become highlighted and the grid will become smoothed quit rapidly. If it is desired to smooth the grid again, repeat the steps. *NOTE: If other block modifications are made on the block that has been smoothed, the smoothing will be replaced by a new grid which can be re-smoothed if desired.*

2.2.5 TIGGERC: Block Menu: Zoom/Translate

The *Zoom/Translation* feature will be discussed in a later section.

2.2.5 TIGGERC: Block Menu: Exit

The *Exit* feature will return to the Main Menu.

2.3 TIGGERC: Flowpath Menu / Station Menu

Once the data have been read into the program, a graphics window will appear with the all the boundaries identified with different symbols. For example, the lower flowpath boundary will be marked with individual squares identifying the point data, while the inlet and exit boundaries are identified by triangles. There are three important main menu picks that can now be used to modify or manipulate the boundary data. They are the *Flowpath Menu*, *Station Menu* and *Edit Tool* options. The code works as a block by block manipulator and has been developed such that little reference to the manual is required to understand the operations of the code.

The *Flowpath* and *Station Menus* are identical and the operational features of these menus will be combined in the discussion below. The options featured in these menus, as shown in Figure 10, have several important selections which allow the user to add points, delete points, move points, spline points, fit a smoothed bezier curve and zoom or translate the graphical figure.

Once the data are in the proper position for modification, select the option desired to obtain the specific changes desired. The options for the menus are: *Add Points*, *Delete Points*, *Move Points*, *Spline Points*, *Use Bezier Curve*, *Zoom/Translate* and *Exit*. For example, as shown in Figure 11, the configuration shown is the NASA Rotor 67[16] meridional flowpath and station information. There are five blocks shown in the example. Looking at the rotor blade, block 2, we notice that the flowpath coordinates are sparse. For demonstration purposes, the *Flowpath Menu* option will be chosen to make a curve modification.

2.3.1 TIGGERC: Flowpath Menu: Add Points

If it is desired to add more points to the flowpath, first, zoom in on the section of the flowpath to add the points. Next, select the *Add Points* option from the menu, then move the mouse cursor over to the flowpath curve and push the left mouse (LM) on the curve which will become highlighted. Next, select the existing points that bound the region for entry with the right mouse button (RM). After the segment end points have been chosen, a question will appear as to whether the added points will be done manually (by keyboard entry). By selecting *NO*, the left mouse button (LM) is used for inputting data as needed. Once the data are complete, push the right mouse button (RM) and the new data are automatically saved and displayed. If the added data are not satisfactory, then the middle mouse button (MM) acts as an *Undo* feature which will exit the *Add Points* option returning

the original curve. Examples are shown in Figures 12a-12f. By selecting **YES**, a positioner will appear in the upper right corner of the workstation (Figure 13). The positioner has an x-position, y-position and cross-hairs for manual entry input. The cross-hairs can add points by moving the cross-hairs with the **left** mouse button (**LM**). The new x and y positions will appear in the boxes. To set the x or y position, place the mouse cursor in the colored number box and by using the *Backspace* key (**BS**) or *Escape* key (**ESC**) to erase the current number, enter the x and y new positions followed by the (**TAB**). Use the **OK** button to accept and continue. Push the **Done** button when finished or the **Undo** button if the points are not acceptable. *PLEASE NOTE: The code does not sort the added data, it expects the input data to be sequential (left to right), if the data were entered non-sequentially, then the data will reflect the input points as they are specified.*

2.3.2 TIGGERC: Flowpath Menu: Delete Points

To delete points from the flowpath, select the delete points option from the menu, then place the mouse over the flowpath curve desired and click on the curve with the **left** mouse button (**LM**). The curve will become highlighted as before. Next select the data point that is to be deleted and click on the data point with the **left** mouse button (**LM**). The point will immediately disappear. The only exceptions are the endpoints of each block. The endpoints are tied to the station endpoints and therefore not allow to be deleted, however, there is a way to delete these points. The station must first be removed from the flowpath and then it is possible to delete the end point. Once all the deletions are complete, push the **right** mouse button (**RM**) and the new curves are saved. See the examples in Figures 14a-14d. If the deletion is not satisfactory, then the **middle** mouse button (**MM**) acts as an *Undo* feature which will exit the option returning the original curve.

2.3.3 TIGGERC: Flowpath Menu: Move Points

To move points on the flowpath, select the *Move Points* option from the menu, then place the mouse cursor on the flowpath in which the points are to be moved and push the **left** mouse button (**LM**). Again the curve will become highlighted. Select the data point that is to be moved and hold down the **left** mouse button (**LM**) on that data point and drag the point around to a desired location. Once the **left** mouse button (**LM**) is released, a new point on the curve can be selected and moved. Sometimes the points are difficult to move to the new location desired. A fine tuning of the speed at which the points can be dragged along has been added as a feature to this option. By using the **up** and **down** arrow keys (**UA**) (**DA**), the sensitivity can be increased (**UA**) or decreased (**DA**).

To move the points by entering the new x and y positions numerically, while selecting the point on the curve, press the **M** key. A positioner, similar to that shown in Figure 13, but without the done and undo button, will appear in the workstation upper right corner. The positioner has an x-position, y-position and cross-hairs for manual entry input. The cross-hairs can move the point by moving the cross-hairs with the **left** mouse button (**LM**). The new x and y positions will appear in the boxes. To set the x or y position, place the mouse cursor in the colored number box and by using the *Backspace* key (**BS**) or *Escape* key (**ESC**) to erase the current number, enter the x and y new positions followed by the (**TAB**). Use the **OK** button to accept and continue. Once the points have been moved to the final positions, push the **right** mouse button (**RM**) and the new curve is retained. Figures 15a-15d demonstrate the move option. The **middle** mouse button (**MM**) acts as an *Undo* feature which will return the original curve.

2.3.4 TIGGERC: Flowpath Menu: Spline Point

To spline the upper or lower (inlet or exit with the Station Menu) boundaries with more points, select the *Spline Points* option from the menu. Move the mouse cursor on the curve desired and push the left mouse button (LM) on the curve. The curve will become highlighted. Next, select the starting and the end point for the section to be splined with the right mouse button (RM). After which, the curve will automatically be splined with a fixed number of points on the curve. A slider will appear in the upper right corner of the workstation, Figure 16, which provides the means to add more or less points to the spline. Move the slider with the left mouse button (LM) to obtain the number of points desired. Placing the mouse cursor in the number box and using the *Backspace* key (BS) or *Escape* key (ESC) to erase the current number. Type in the desired number followed by the *TAB* button (TAB), which will save and display the selected number of points on the curve. An *Undo* button has been added to undo the spline. Once the spline is complete, push the *Done* button and the new curve is retained. Examples of the spline are shown in Figures 17a-17h.

2.3.5 TIGGERC: Flowpath Menu: Use Bezier Curve

To change the shape of a segment, instead of adding points on the exiting shape, select the *Use Bezier Curve* option from the menu. Move the mouse cursor to the curve to be modified and push the left mouse button (LM). The curve becomes highlighted. Select the starting and end points with the right mouse button (RM) where the Bezier curve will be applied. After which, a straight line Bezier curve with a fix number of points will appear on the curve with two control points highlighted. The slider, Figure 16, will appear in the upper right corner of the workstation. By moving the control points

around with the left mouse button (LM), new curves are generated. This provides a significant degree of freedom in creating curved surfaces. There is an *Undo* button which can undo the curve before leaving this option. Once the Bezier curve is finished, push the *Done* button and the new curve is saved. Examples are shown in Figures 18a-18h.

2.3.6 TIGGERC: Flowpath Menu: Zoom/Translate

The *Zoom/Translation* feature will be discussed in a later section.

2.3.7 TIGGERC: Flowpath Menu: Exit

The *Exit* feature will return to the Main Menu.

The illustrations that have been shown are also applicable to the *Station Menu* as well. The only differences between flowpath and station menus are the boundaries you can select. The *Flowpath Menu* only allows the user to select upper and lower boundaries of the block while the *Station Menu* only allows modification of the inlet and exit boundaries.

2.4 TIGGERC: Edit Tools

A tool kit has been added to enhance some of the capabilities of the grid generator which allows the user to *Add a Block*, *Delete a Block*, *Scale Geometry*, *Change the default Setup*, and *Zoom/Translate* (see Figure 19).

2.4.1 TIGGERC: Edit Tools: Add a Block

This option will split existing blocks, but not rows. Also, the user cannot add a block to the inlet or end of the existing geometry with this option. The procedure of adding a block is also subject to the requirement that there is enough existing boundary data to add the additional block. If there are no data points on the boundaries, it will be necessary to spline or add some data points on the boundaries before you

can add an additional block. An example of adding a block will be illustrated as follows. In Figure 11, there are 5 separate blocks shown. An Additional block will be added to Block 3. The gap is between the rotor and the stator. *Zoom/Translate* in on the area and then select the *Add a Block* button. Push the **left mouse button (LM)** while touching the lower boundary curve of the block. The upper and lower boundaries will become highlighted to indicate which block has been selected. At this point, select the point where the block will be added with the **right mouse button (RM)** on the lower boundary for the beginning segment of the new block and the end segment point with the **right mouse (RM)** on the upper boundary. These points will be highlighted when selected. After the boundaries have been selected, the block will no longer be highlighted. Push the **middle mouse button (MM)** and a new boundary appears splitting the existing block into two new blocks. (See Figures 20a-20d) The **middle mouse button (MM)** can act as an *Undo* button until the two boundary points have been selected. For example, if the new block being added was not located as desired, the **middle mouse button (MM)** can be used to undo the option.

For more than one row, TIGGERC was written such that all the adjacent blocks in each row must be split if a new block is to be added. The blocks must be split starting from the bottom row. Split the bottom block first using the procedure above, next split the adjacent block above that block until the outer row has been reached. The only difference in the procedure above from multiply row splits is that the middle mouse is not used until the last row has been split, otherwise the middle mouse will undo the splitting.

2.4.2 TIGGERC: Edit Tools: Delete a Block

Select *Delete a Block* button, then move the mouse cursor to a inlet or exit boundary which represents the division of two blocks and push the **left mouse button (LM)**. The boundary will disappear leaving the new block. There is *NO UNDO* button for this option. Repeating, There is *NO UNDO* button for this option. If there has been an error in the block deletion, the *Add a Block* option described above must be used to replace the deleted block. If you delete a block that is the inlet or exit to the geometry, in which case the geometry will be lost. Some examples are shown in Figures 21a-21b.

2.4.3 TIGGERC: Edit Tools: Scale Geometry

This option allows the geometry to be scaled. Select this option and input the scaling factor which will uniformly scale the geometry up or down.

2.4.4 TIGGERC: Edit Tools: Change Setup

A standard set of parameters are needed to generate points on curves, establish plotting minimum and maximum values, spline parameters, block grid parameters, and set the Titles. (Figure 22) To change any of these parameters, select the *Change Setup*, a new menu will appear with all the parameters that can be changed in the list. To change any parameter, move the mouse cursor to the parameter to be changed and by using the *Backspace Key (BS)* or *Escape* button (**ESC**), the parameter will disappear and a new parameter can be input into the box. Once the new parameter has been input, type the *TAB* button (**TAB**) which will save the input. The minimum and maximum x-axis and y-axis values shown are computed from the input data set. They can be modified to what ever minimum and maximum values the user wishes to specify. The number of divisions on the axis can be altered and the symbol sizes can be changed from this menu. The maximum number

of points for spline and Bezier curve computations can be changed as well as with the maximum number of block and spanwise points. *CAUTION: The maximum allowable points for each block is related to the parameter.gn file used to compile the code. These maximum values have been set to a maximum of 200 for axial block points and a maximum of 101 for spanwise points.* The option to save the setup changes can be done by pushing the *Save* button. This will write a setup file in the current directory and use the setup file when TIGGERC is restarted from the window. If no setup file exists the code will establish its own internal default values.

2.4.5 TIGGERC: Edit Tools: Zoom/Translate

The *Zoom/Translation* feature will be discussed in a later section.

2.4.6 TIGGERC: Edit Tools: Exit

The *Exit* feature will return to the Main Menu.

2.5 TIGGERC: Zoom/Translate

The *Zoom/Translate* option operates exactly like the mouse zoom and translate features in the plot3d plotting package[9]. Select this option and place the mouse cursor in the graphics window before depressing a mouse button. The middle mouse button (MM) pressed while pulling the mouse down enlarges the figure and pushing upward shrinks the figure. To translate the figure, push the right mouse button (RM) and while pulling left pulls the figure left and pulling right moves the figure right. Translations can be done in any direction. The left mouse button (LM) disengages the zoom and translate button. A sensitivity feature has also been included to speed up or slow down the zoom and translating of the figure. The up and down arrows (UA) (DA) on the keyboard allow some fine tuning features: each up arrow press increases the sensitivity while each down arrow press

decreases sensitivity. Zooming and translating are the most frequently used options and have been included on every menu.

2.6 TIGGERC: Write Output

To save the modifications or generate a grid, choose the option to *Write Output Files*. Place the mouse over the *Write Output Files* button and hold down the right mouse button (RM) and a pull down menu to select either *2-D Grid* or *2-D File* will appear. The *2-D File* option will generate a new input file or over-write the old input file. It is advisable to save this file as frequently as possible when boundary and grid modifications have been made. The *2-D Grid* option writes the final grid. The grid code will ask if the grid is to be rectilinear or cylindrical and whether or not to write a non-dimensional grid. As a matter of reference, the grid code was design for cylindrical coordinates r , θ , z , however, the grid is written as (x,y,z) with $x = z$, $y = r \cos\theta$ and $z = r \sin\theta$. This was done to accommodate Plot3d viewing. For a rectangular grid, $x = z$, $y = r \sin\theta$ and $z = r \cos\theta$. The grid will be written with x , y , and z as though it were a 3-D grid even though the θ variation doesn't really exist. The grid was written in such a way that the flow solution could be written compatible with a preliminary guess to the full 3-D solution of the flow field even though the grid is really 2-D. That is to have the q-file compatible with three components of velocity not just two.

The input data for TIGGERC must be constructed in such a way as to produce the grid in the coordinate system used by the flow solver. Basically, if the grid needs to be specified in rectangular coordinates, x , and y , then write the grid as a cylindrical grid because θ is zero, otherwise, the grid will be written as x and z . To understand this, Plot3d reads a grid and flow file when plotting a 3-D flow field. The flow file is written as

$$Q = \begin{bmatrix} \rho \\ \rho u \\ \rho v \\ \rho w \\ \rho e \end{bmatrix} \quad (33)$$

where the flow quantities u , v and w are the axial, radial and tangential velocities being computed for typical turbomachinery problems.

This concludes the discussion on the general operational features of the grid generation package.

2.7 TIGGERC: QUIT

To quit TIGGERC, push the Quit button. A final question will ask the user to confirm the quit or return to the main menu.

3.0 Sample Grids

TIGGERC was primarily written to generate H-grids, however, since the code was written such that the grid is generated block-by-block, any type of grid could be generated such as C-grid, O-grid or even an I-grid. There are several examples of typical geometries which could be gridded using TIGGERC. The examples are included with the executable code. The following input are included to illustrate the code's ability to generate the various types of grids discussed above: Demo_H-Grid_r67.inp, Demo_H-Grid_adp.inp, Demo_C-Grid_NACA_64-410.inp, Demo_O-Grid_NACA_64-410.inp, and Demo_I-Grid_turbine.inp. H-type grid generation is extensively used in TIGGERC, as demonstrated by the following two examples.

For typical turbomachinery problems, such as rotor67 with the boundary points identified, it is easy to generate a typical grid (Figure 23). This grid consists of only 1 row and 5 blocks. Another more complex H-type Grid was generated for an advance ducted propfan as shown in Figure 24a.

This grid was generated from 3 rows and 21 blocks. The interesting aspect about this grid is the flow splitter and cowling. The grid has to be generated such that the nose of the splitter and the lip of the cowling are preserved as accurately as possible. To obtain an accurate grid, it becomes important to put as many grid points as possible in the high curvature regions as shown in Figures 24b-24c. This grid is a strict H and shows the difficulty in resolving leading edges of critical geometry.

It is not always desirable to have a H-grid for computational purposes, for example, external aerodynamics have typically used C-grids and O-grids. Since TIGGERC was a generic block grid code, almost any type of grid can be generated with the exception of an unstructured grid. A NACA 64-410 airfoil was used to demonstrate the codes ability to generate not only H-grids but C and O as well. Figures 25 and 26 are examples of the type of C-grid and O-grid which can be generated with TIGGERC. Another grid not commonly used but useful in some turbine geometries where there is large turning angles and blunt leading and trailing edges is an I-grid. This type of grid is useful in obtaining orthogonal blade-to-blade grids but also complicates the flow solution because the periodic boundary must be interpolated due to the grid. An example of an I-grid is shown in Figure 27.

4.0 Concluding Remarks

A two-dimensional interactive grid generation package has been developed for use in turbomachinery flow problems. The grids can be generated for multiple blade rows and multiple blocks for various configurations as previously shown. The code has been provided with several user interfaces which make the code interactive. The grid generator also acts as a flowpath geometry modeler which can aid designers in smoothing flowpaths, correct for flow separations, model splitters, etc. The code

functions primarily as a grid code for axisymmetric turbomachinery problems but, has been developed to assist designers in flowpath geometry modeling as well.

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APPENDIX A

Program Implementation and Sample Data File

A.1.0 Introduction

As previously discussed, TIGGERC was written for Unix™ Workstations and primarily Silicon Graphics™ Workstations. The principle distribution is via a compressed tar file and can be obtained as a floppy disk or 90m tape. To retrieve the code "uncompress tiggerc.tar.Z" and then specify "tar xvf tiggerc.tar". The executable file "tiggerc" can be found in /exe, while the source listings can be found in /src and sample data files in /data. To compile the source code, change directories to /src and specify "make". If the parameter dimensions are too small make the appropriate changes to parameter.gn, common.h, and ellpsrc.com, then run the makefile.

A.1.1 Sample Data

A set of sample data files can be found in /data directory. The following data file was generated using Rotor67 through flow coordinates. The top line has a restart flag which is set to 2. The next section consists of 5 lines of description. The number of rows are then specified followed by the total number of blocks. Then the flowpath coordinates of each block are entered followed by the stations representing the end of the each block and finally general block data which includes the number of points per block, number of blades if the block contains a blade row, stretching parameters at the leading and trailing edges and finally the spanwise block parameters for each block. The following data set can be found in Demo_H-Grid_r67.inp.

-----BEGIN Demo_H-Grid_r67.inp-----

```

2
+-----begin-----+
Rotor67 axisymmetric geometry coordinates
Tigg-c Demonstration Input file
File created for Tigg-c Demo Input
Date June 15, 1993
Test Data for Distribution
*****number of rows*****
1
*****number of blocks*****
5
*****Flowpath input coordinates*****
+shroud sec.      1+--nsec-----+-----npts-----+
1      7
+-----Z-----+-----r-----+
-14.00000    10.10000
-6.000000    10.10000
-1.824000    10.10000
-1.110000    10.10000
-1.100000    10.10000
-0.2000000   10.08000
0.1700000    10.05100
+shroud sec.      2+--nsec-----+-----npts-----+
2      4
+-----Z-----+-----r-----+
0.1700000    10.05100
0.5270000    10.00000
1.100000     9.870000
1.765000     9.748000
+shroud sec.      3+--nsec-----+-----npts-----+
3      6
+-----Z-----+-----r-----+
1.765000     9.748000
2.700000     9.650000
3.485000     9.621000
4.000000     9.600000
4.010000     9.600000
4.116000     9.600000
+shroud sec.      4+--nsec-----+-----npts-----+
4      2
+-----Z-----+-----r-----+
4.116000     9.600000
6.353000     9.600000
+shroud sec.      5+--nsec-----+-----npts-----+
5      9
+-----Z-----+-----r-----+
6.353000     9.600000
7.300000     9.600000
7.310000     9.600000
8.400000     9.600000

```

9.150000	9.600000
9.900000	9.600000
10.60000	9.600000
10.61000	9.600000
14.00000	9.600000
+hub sec.	1+-----nsec-----+-----npts-----+
1	13
+-----Z-----+-----I-----+	
-14.00000	3.750000
-12.80000	3.750000
-12.79000	3.750000
-11.30000	3.725000
-9.900000	3.675000
-7.800000	3.600000
-5.700000	3.525000
-4.800000	3.500000
-4.790000	3.500000
-2.000000	3.580000
-1.824000	3.600000
-1.250000	3.690000
-0.8550000	3.771000
+hub sec.	2+-----nsec-----+-----npts-----+
2	5
+-----Z-----+-----I-----+	
-0.8550000	3.771000
0.0000000	4.000000
1.000000	4.320000
2.500000	4.630000
2.727000	4.658000
+hub sec.	3+-----nsec-----+-----npts-----+
3	4
+-----Z-----+-----I-----+	
2.727000	4.658000
3.485000	4.731000
3.700000	4.750000
4.192000	4.799000
+hub sec.	4+-----nsec-----+-----npts-----+
4	3
+-----Z-----+-----I-----+	
4.192000	4.799000
5.300000	4.940000
6.348000	5.092000
+hub sec.	5+-----nsec-----+-----npts-----+
5	12
+-----Z-----+-----I-----+	
6.348000	5.092000
6.700000	5.120000
6.800000	5.124000
7.600000	5.140000
8.700000	5.140000
9.500000	5.140000

```

9.900000  5.140000
10.70000  5.140000
11.30000  5.140000
13.59000  5.140000
13.60000  5.140000
14.00000  5.140000
*****station input data*****
+--station---+---id---+---idtype---+---nst---+
  1.0000000  inlet   le      2
+-----z-----+-----r-----+
-14.00000    3.750000
-14.00000    10.10000
+--station---+---id---+---idtype---+---nst---+
  2.0000000  inlet   te      13
+-----z-----+-----r-----+
-0.8550000    3.771000
-0.8390000    3.892000
-0.6790000    4.942000
-0.5560000    5.761000
-0.4500000    6.458000
-0.3400000    7.077000
-0.2500000    7.640000
-0.1720000    8.162000
-9.8999999E-02 8.653000
-3.0999999E-02 9.118000
 3.9999999E-02 9.562000
 0.1580000    10.00800
 0.1700000    10.05100
+--station---+---id---+---idtype---+---nst---+
  3.0000000  rotor1  le      13
+-----z-----+-----r-----+
-0.8550000    3.771000
-0.8390000    3.892000
-0.6790000    4.942000
-0.5560000    5.761000
-0.4500000    6.458000
-0.3400000    7.077000
-0.2500000    7.640000
-0.1720000    8.162000
-9.8999999E-02 8.653000
-3.0999999E-02 9.118000
 3.9999999E-02 9.562000
 0.1580000    10.00800
 0.1700000    10.05100
+--station---+---id---+---idtype---+---nst---+
  4.0000000  rotor1  te      13
+-----z-----+-----r-----+
 2.727000    4.658000
 2.720000    4.759000
 2.666000    5.454000
 2.555000    6.058000

```

2.383000	6.604000
2.254000	7.113000
2.143000	7.592000
2.042000	8.044000
1.976000	8.476000
1.920000	8.889000
1.870000	9.290000
1.777000	9.696000
1.765000	9.748000

station	id	idtype	nst
5.0000000	gap1	le	13

Z	I
2.727000	4.658000
2.720000	4.759000
2.666000	5.454000
2.555000	6.058000
2.383000	6.604000
2.254000	7.113000
2.143000	7.592000
2.042000	8.044000
1.976000	8.476000
1.920000	8.889000
1.870000	9.290000
1.777000	9.696000
1.765000	9.748000

station	id	idtype	nst
6.0000000	gap1	te	13

Z	I
4.192000	4.799000
4.190000	4.920000
4.175000	5.603000
4.162000	6.184000
4.151000	6.705000
4.143000	7.182000
4.135000	7.625000
4.129000	8.041000
4.124000	8.437000
4.120000	8.815000
4.114000	9.179000
4.116000	9.539000
4.116000	9.600000

station	id	idtype	nst
7.0000000	stator1	le	13

Z	I
4.192000	4.799000
4.190000	4.920000
4.175000	5.603000
4.162000	6.184000
4.151000	6.705000
4.143000	7.182000
4.135000	7.625000

```

4.129000    8.041000
4.124000    8.437000
4.120000    8.815000
4.114000    9.179000
4.116000    9.539000
4.116000    9.600000
+--station---+--id---+--idtype---+--nst---+
  8.0000000  stator1  te    13
+-----Z-----+-----I-----+
6.348000    5.092000
6.347000    5.221000
6.343000    5.822000
6.342000    6.350000
6.342000    6.830000
6.342000    7.276000
6.343000    7.696000
6.343000    8.093000
6.344000    8.472000
6.345000    8.837000
6.347000    9.189000
6.352000    9.531000
6.353000    9.600000
+--station---+--id---+--idtype---+--nst---+
  9.0000000  exit    le    13
+-----Z-----+-----I-----+
6.348000    5.092000
6.347000    5.221000
6.343000    5.822000
6.342000    6.350000
6.342000    6.830000
6.342000    7.276000
6.343000    7.696000
6.343000    8.093000
6.344000    8.472000
6.345000    8.837000
6.347000    9.189000
6.352000    9.531000
6.353000    9.600000
+--station---+--id---+--idtype---+--nst---+
 10.0000000  exit    te     2
+-----Z-----+-----I-----+
 14.00000    5.140000
 14.00000    9.600000
*****general information*****
+nbkp+nb+sle--+ste--+dle--+dte--+dlec--+dtec--+slec--+stec--+
 30   0   1.0   1.0   0.2   0.05  0.2   0.05   1.0   1.0
 15   0   1.0   1.0   0.2   0.05  0.2   0.05   1.0   1.0
 40  22   1.0   1.0   0.2   0.05  0.2   0.05   1.0   1.0
 15   0   1.0   1.0   0.2   0.05  0.2   0.05   1.0   1.0
  8   0   1.0   1.0   0.2   0.05  0.2   0.05   1.0   1.0

```


+nsp+	srh--	+srs--	dxh--	dxs--	+
31	1.0	1.0	0.10	0.10	
31	1.0	1.0	0.10	0.10	
31	1.0	1.0	0.10	0.10	
31	1.0	1.0	0.10	0.10	
31	1.0	1.0	0.10	0.10	

+-----end of flowpath-----+

-----END Demo_H-Grid_r67.inp-----

There is no batch operation of the code. A Quick Reference Users Guide has been provided in Appendix B.

APPENDIX B

Quick Reference Users Guide

B.1.0 TIGGERC: Main Menu

Main Menu	
Start	
Block Menu	←⌋
Flowpath Menu	←⌋
Station Menu	←⌋
Edit Tools	←⌋
Zoom/Translate	←⌋
Write Output Files	
Quit	←⌋

The options are listed in the order as they appear with a square bracket to indicate a pull down or question and the arrows to indicate a sub-menu.

TIGGERC uses the forms library for the user interface. The left mouse button selects the menu item. Text can also be highlighted with left mouse (LM). The (TAB) enters the next field. WARNING: The ENTER key closes the input panel without initiating the input.

Figure A1 shows a complete layout of the menus used in TIGGERC.

Main Menu Architecture

Start

2-D Scratch

2-D File

Block Menu

Block Grid Mod

Span Grid Mod

Plot Grid

Elliptical

Zoom/Translate

Exit

Flowpath Menu

Add Points

Delete Points

Action/Function

With (RM) a pull down menu will include a 2-D Scratch or 2-D file request.

Will ask for input data from the keyboard to the number of rows and blocks and the boundary coordinates.

Will pop a file selector for input.

Generates the grid and pops a menu to modify grid block definitions

With the mouse cursor use (LM) to chose the block for grid modification and a slider will appear allowing points and stretching to be modified.

With the mouse cursor use (LM) to chose the row for grid modification and a slider will appear allowing points and stretching to be modified.

(LM): Toggle between (Plot Grid), (Plot Both), and (Plot Block Boundaries). (RM) pull down menu for selection.

With the mouse cursor use (LM) to chose the block to be elliptical smoothed.

(LM) selects button, use (MM) to Zoom, (RM) to translate and (LM) to exit function.

(LM) select button, return to Main Menu.

A menu to modify upper or lower block boundaries.

With the mouse cursor (LM) to chose the segment for adding points and then (RM) to select the start and end points of the segment. Then (LM) or the Positioner to add the points. (RM) saves and (MM) cancels.

With the mouse cursor use (LM) to chose the segment to delete the points and then (LM) for point deletion. (RM) saves the deletion and (MM) cancels. CAUTION: You Can Delete TOO MANY POINTS.

Move Points	With the mouse cursor (LM) to chose the segment to move the points and then (LM) held down move the point to new position or (M) key with (LM) to use the Positioner. (RM) saves the move. (MM) cancels. NOTE: (UA) increases the translational speed of the move and (DA) decreases the speed.
Spline Points	With the mouse cursor (LM) to chose the segment to be splined. (RM) to select the beginning and end points for the new spline. A slider will appear to add or reduce the number of spline points. The Undo button cancels the spline while the Done button accepts the spline.
Use Bezier Curve	With the mouse cursor (LM) to chose the segment for a Bezier curve. (RM) to select the beginning and end points of the Bezier curve. A slider will appear to add or reduce the number of points on the Bezier curve. (LM) will move the two control points for Bezier curve changes. The Undo button cancels the Bezier Curve while the Done Button accepts the new curve.
Zoom/Translate	(LM) select button, use (MM) to Zoom, (RM) to translate and (LM) to exit function.
Exit	(LM) selects button, return to Main Menu.
Station Menu	A menu to modify inlet or exit block boundaries. This menu has the same buttons as the Flowpath Menu. See Descriptions Above.
Edit Tools	A tool kit to add and delete blocks and general setup changes.
Add a Block	This option splits a block into two blocks with a vertical cut. (LM) selects the block. For multiple rows, select the block on the 1st row first. Use (RM) to select point on the lower boundary first follow by (RM) on upper boundary. Continue up the rows (LM) selects the block (RM) (RM), etc. Once the points have been selected, (MM) will automatically split the blocks. (MM) acts as an undo button before points have been selected.

Delete a Block	With the mouse cursor select a boundary, (LM) will delete the boundary. if the front or back boundary of the domain is chosen, the segment will be deleted.
Scale Geometry	A scale factor is input in the shell window.
Change Setup	A parameter menu pops up that controls the plot titles, spline parameters, display min/max values, axis tick marks, axial and span-wise grid stretching types and the maximum axial and radial block points. Save button saves the data in a setup file for restart. Done button save in memory.
Zoom/Translate	(LM) selects button, use (MM) to Zoom, (RM) to translate and (LM) to exit function.
Exit	(LM) selects button, return to Main Menu.
<i>Zoom/Translate</i>	(LM) selects button, use (MM) to Zoom, (RM) to translate and (LM) to exit function.
<i>Write Output Files</i>	A pull down menu will appear asking for whether a 2-D file or 2-D Grid be written.
2-D GRID	Writes a 2-D mesh in the following forms: <ol style="list-style-type: none"> 1. - Rectilinear Grid File 2. - Cylindrical Grid File 3. - 2-D Blade-to-Blade Grid File The mesh files are in binary in plot3d multi-grid format.
2-D File	Writes an input file for TIGGERC.
<i>Quit</i>	Confirm YES or NO.

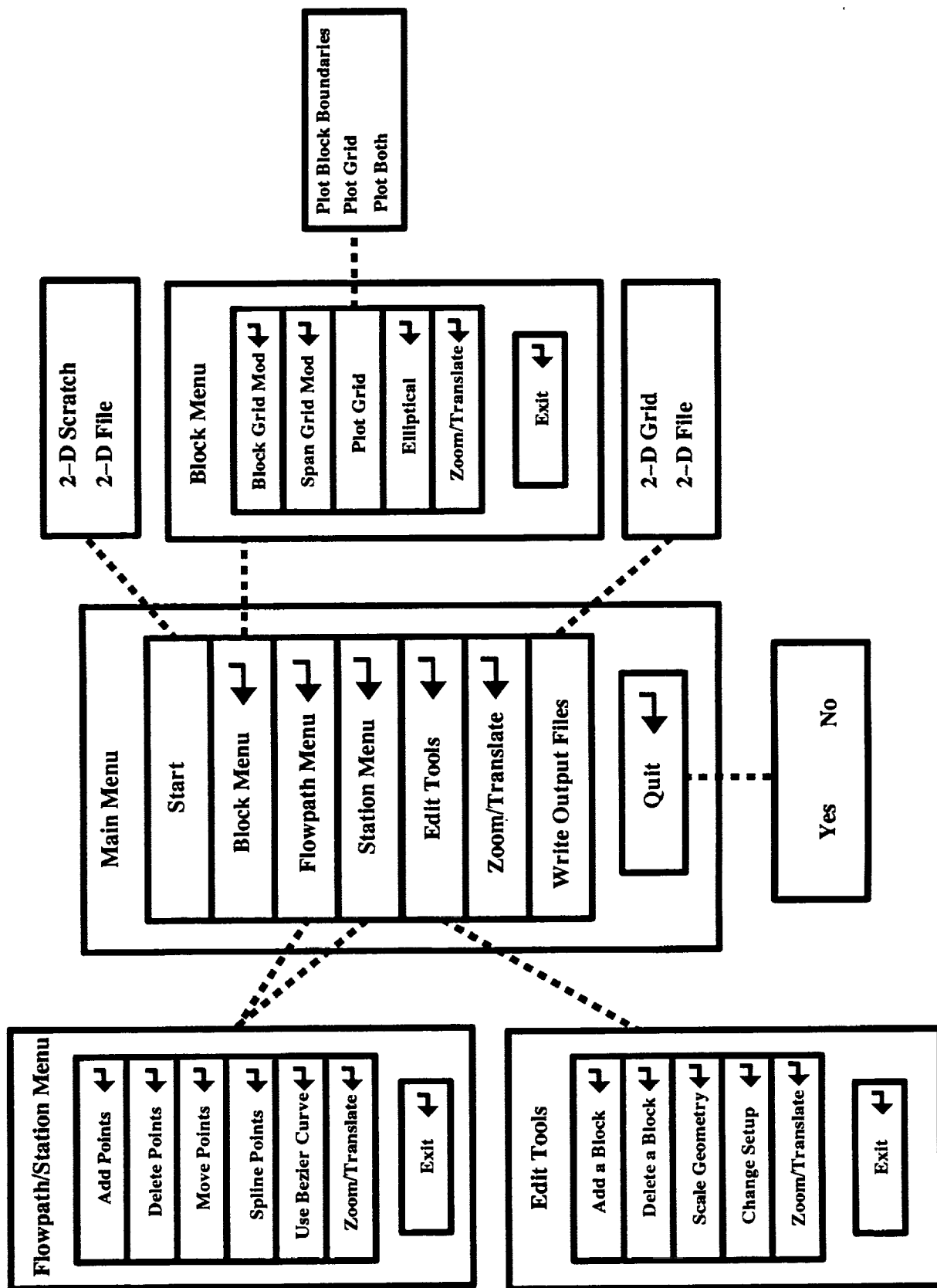


Figure A1: Tiggerc Menu Layout

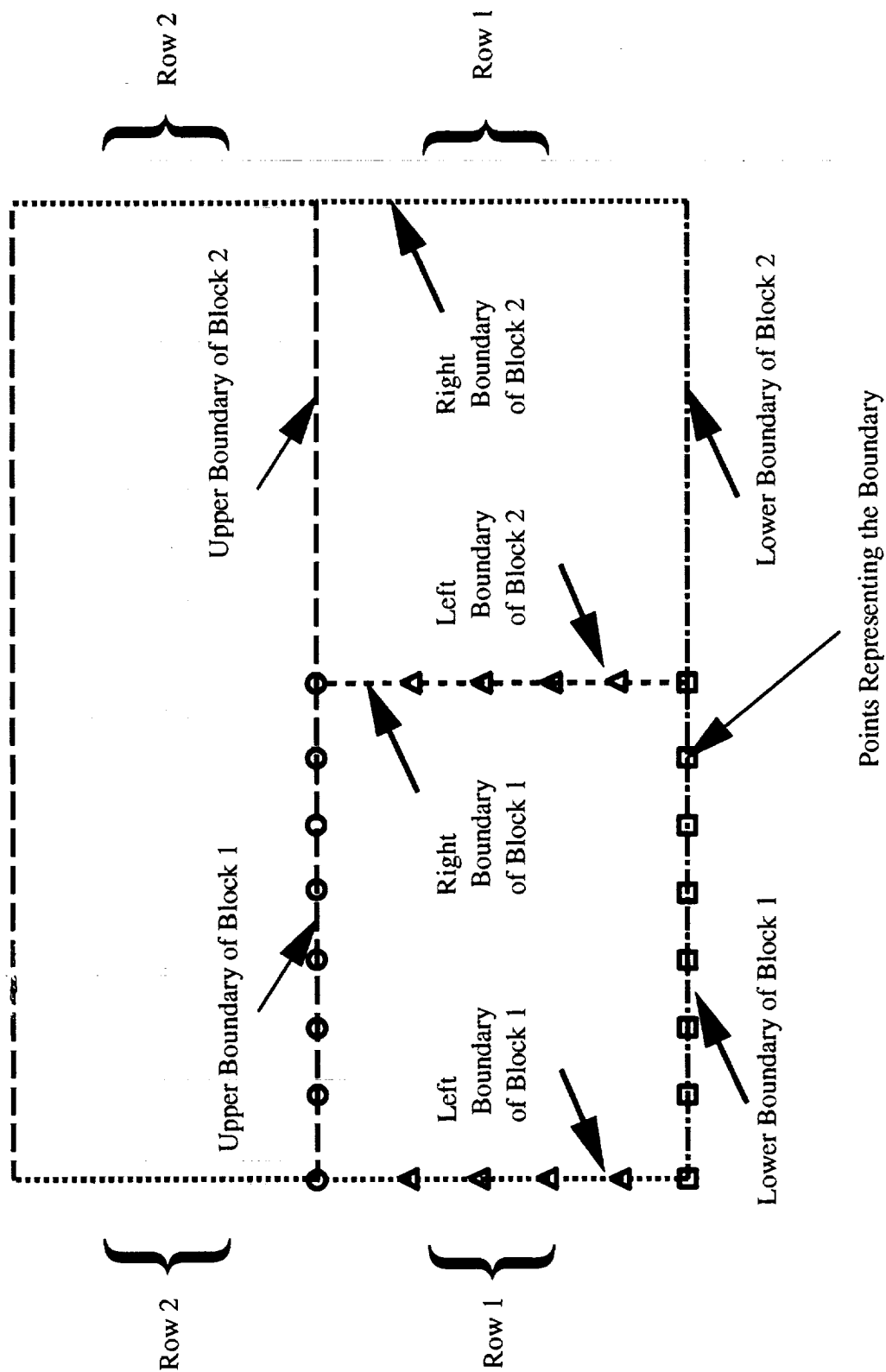


Figure 1: Illustration of Rows and Blocks

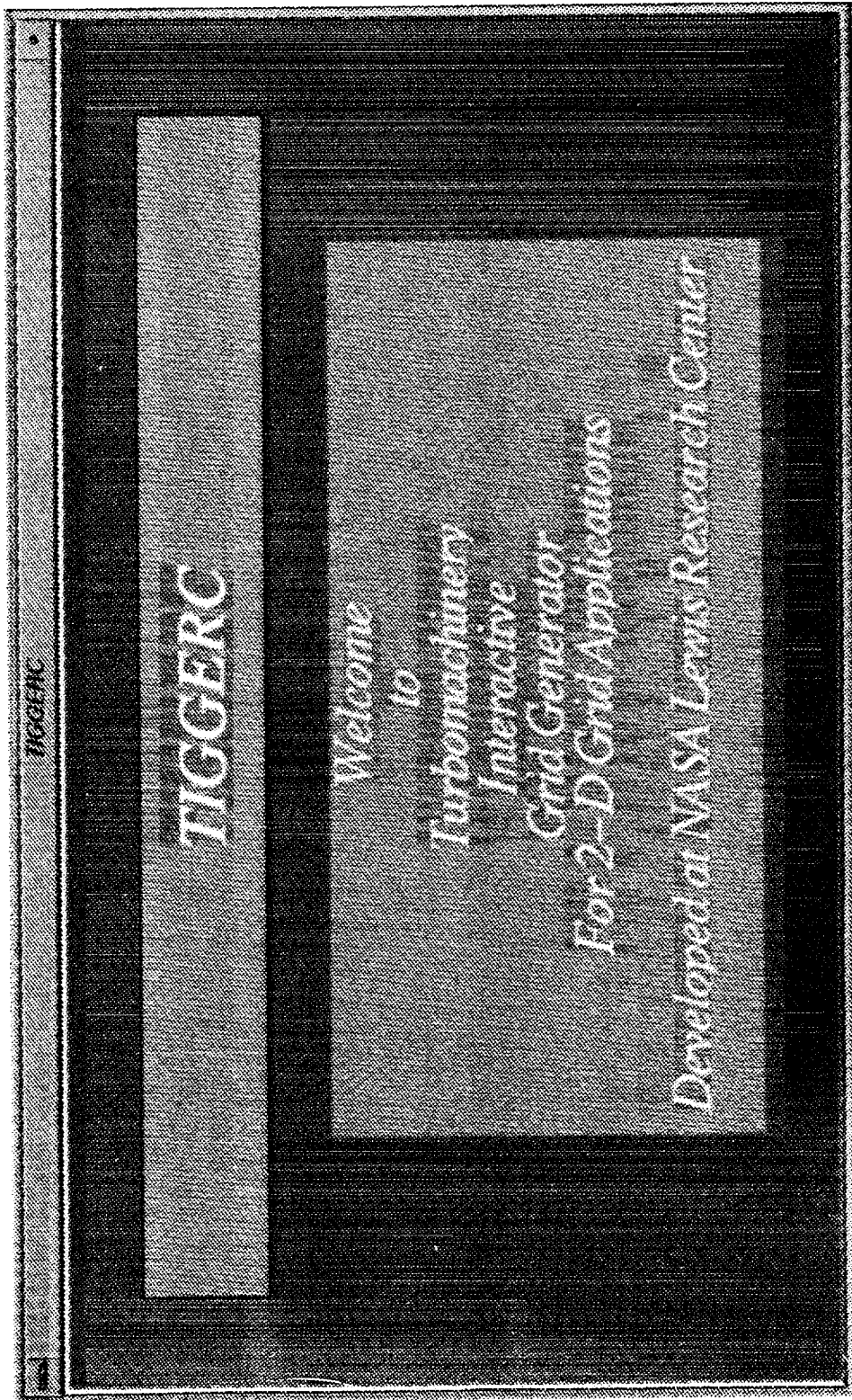


Figure 2a: TIGGERC Main Logo

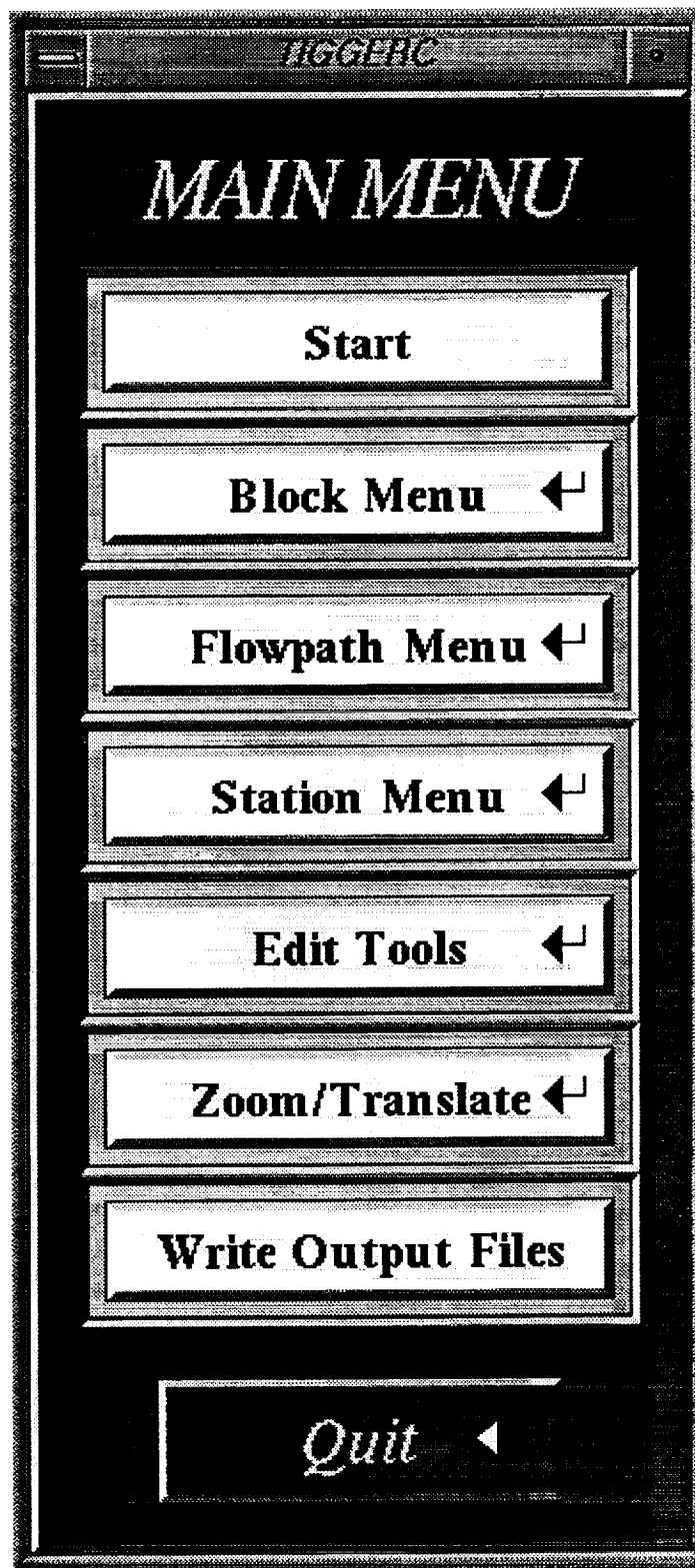


Figure 2b: TIGGERC Main Menu

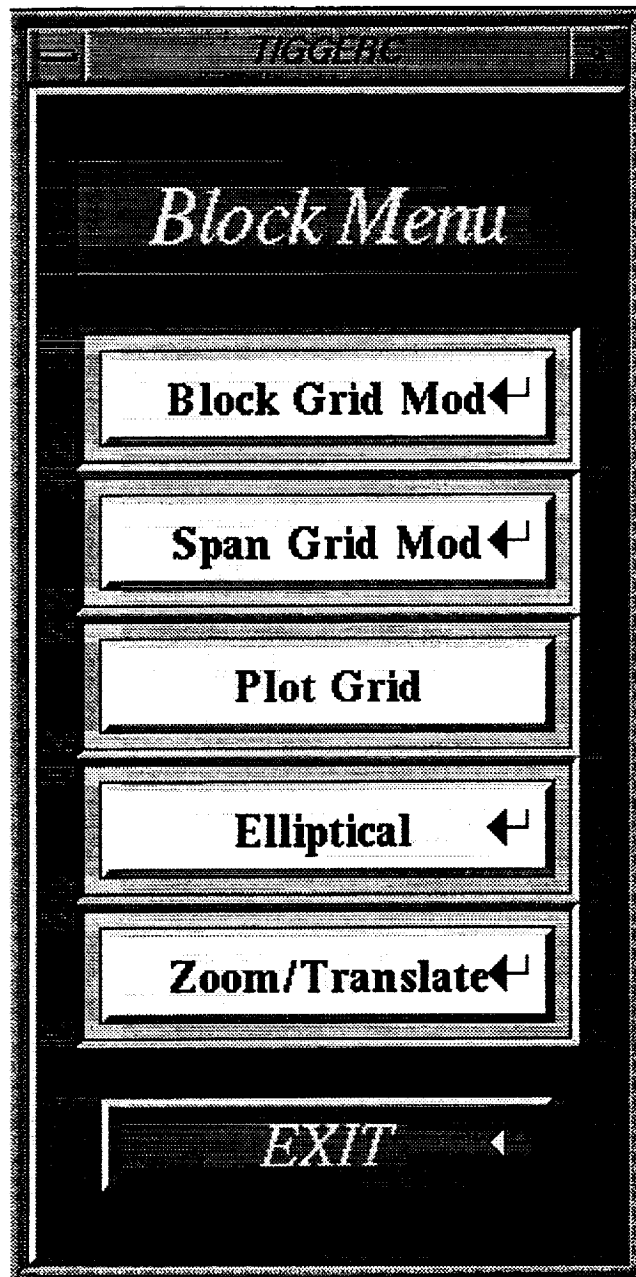


Figure 3: Block Menu

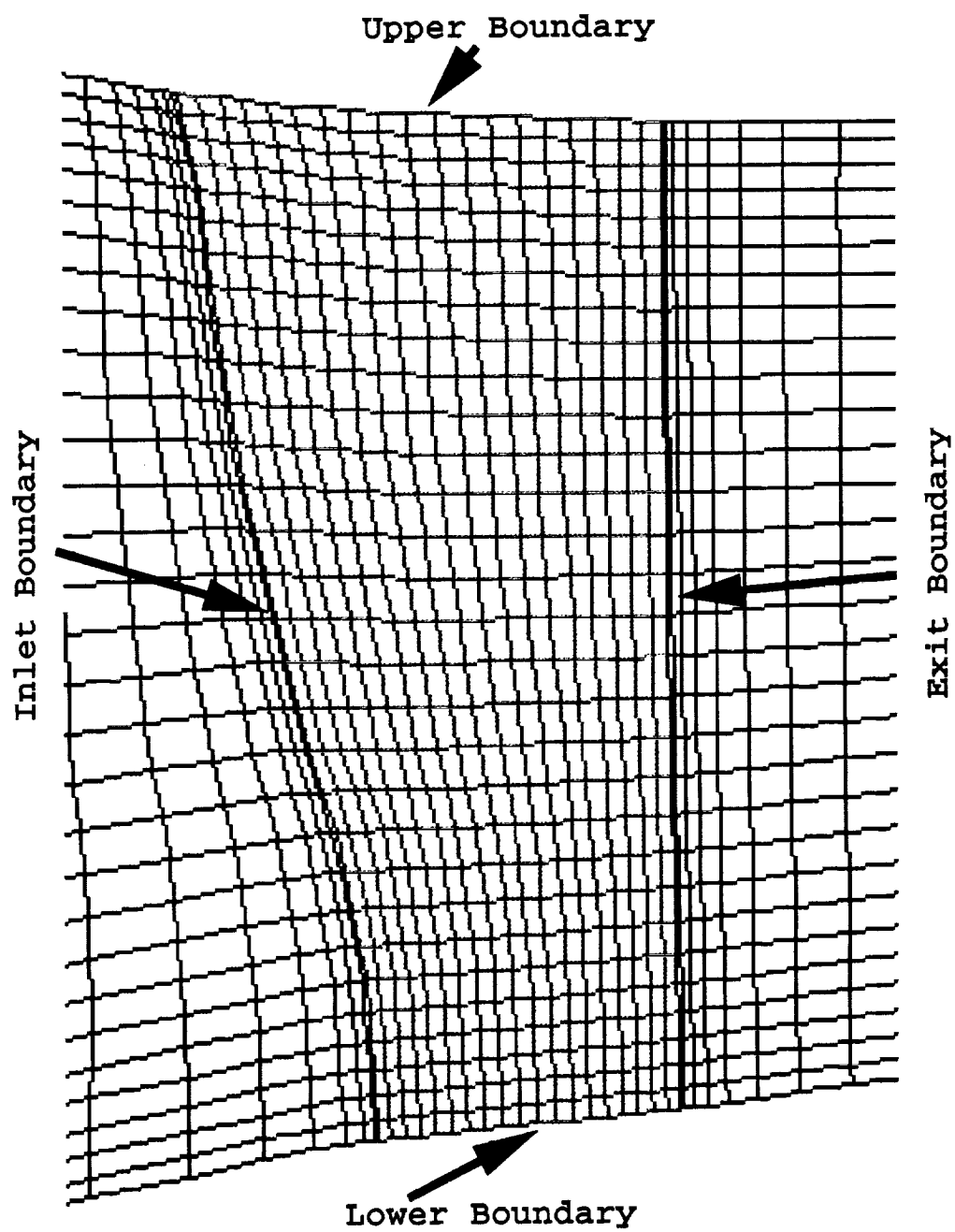


Figure 4: Block Highlighted

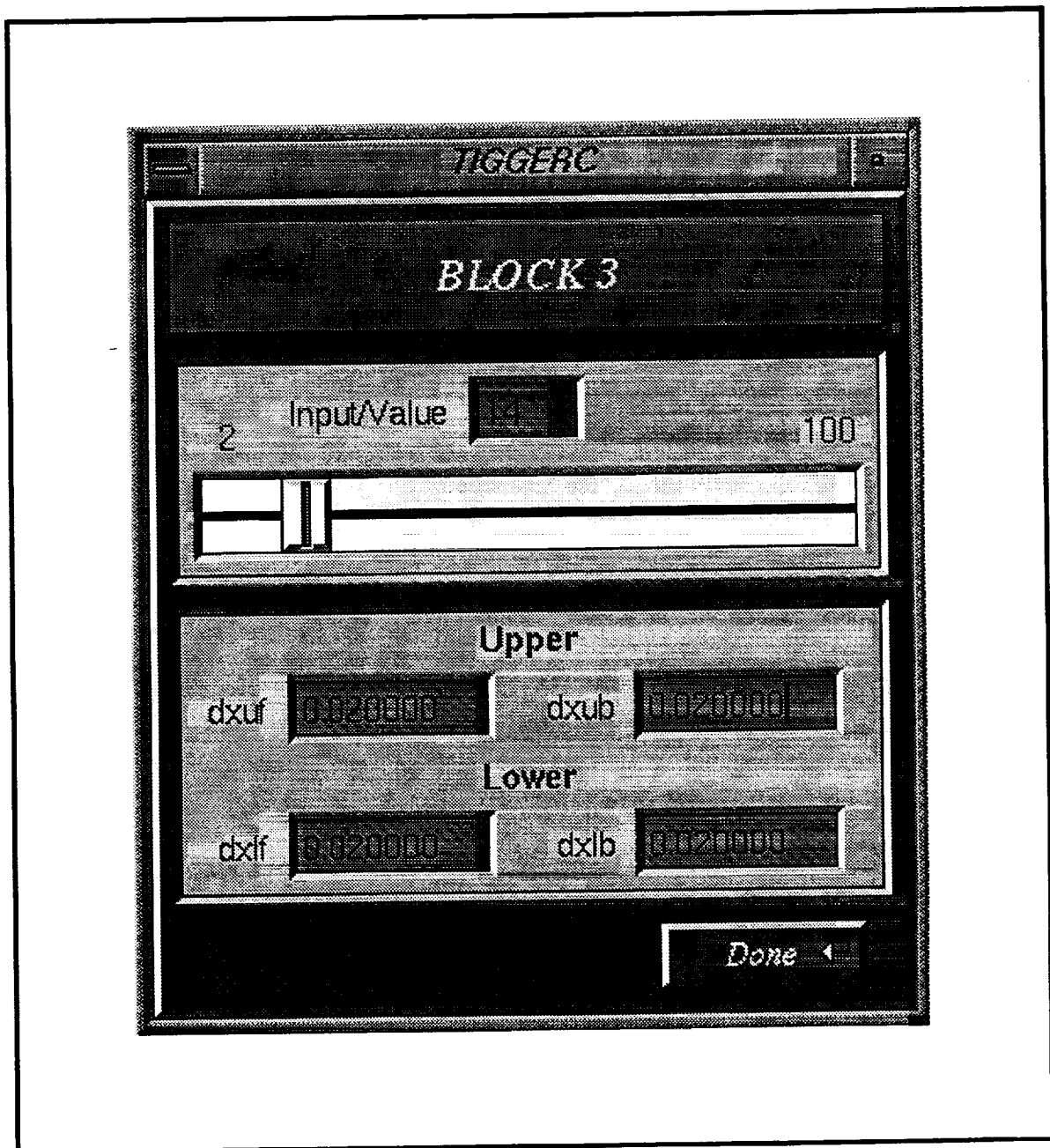


Figure 5: Slider to Modify the Grid Block

10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----

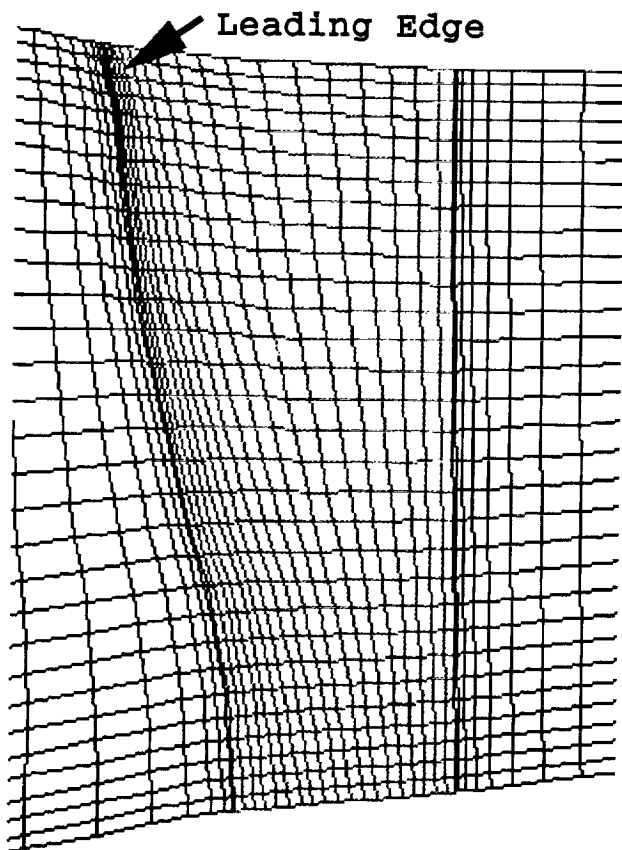


Figure 6a: Modified Upper Leading Boundary Spacing

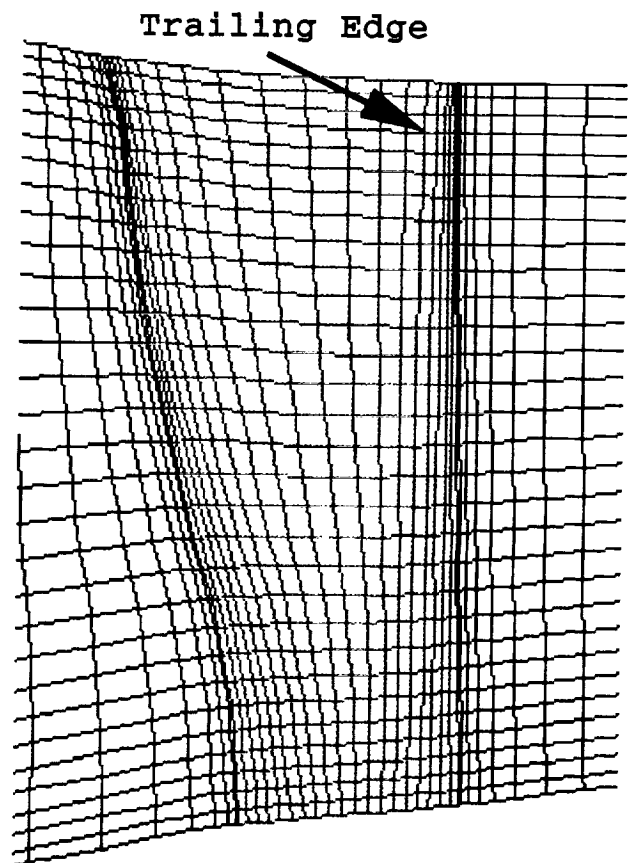


Figure 6b: Modified Upper Trailing Boundary Spacing

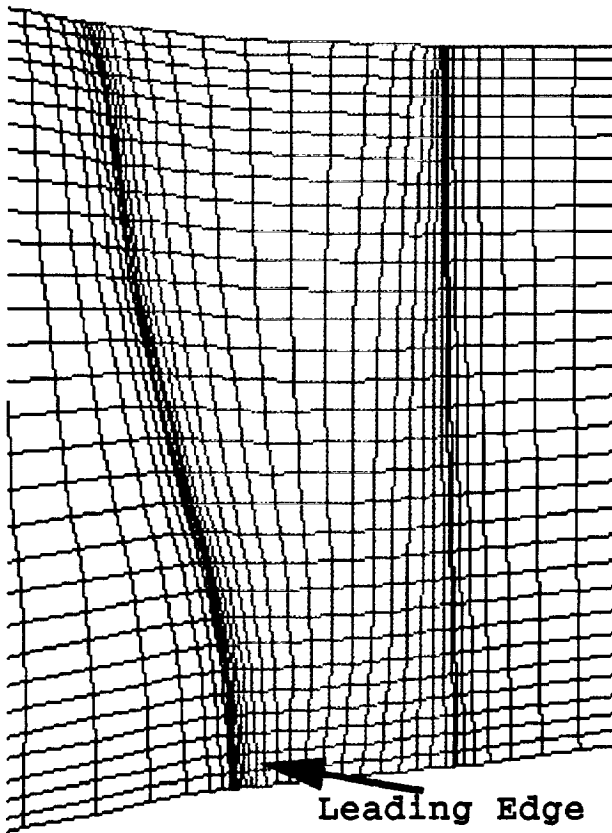


Figure 6c: Modified Lower Leading Boundary Spacing

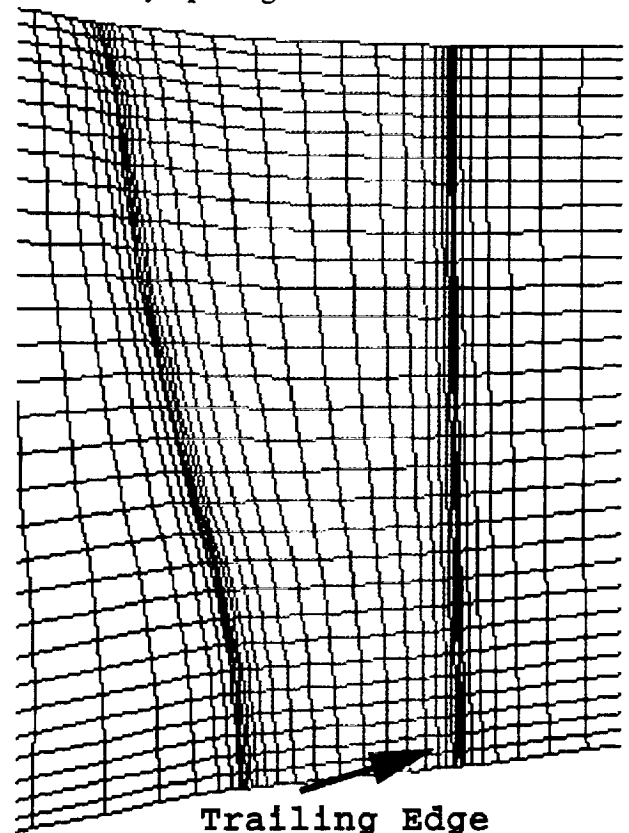


Figure 6d: Modified Lower Trailing Boundary Spacing

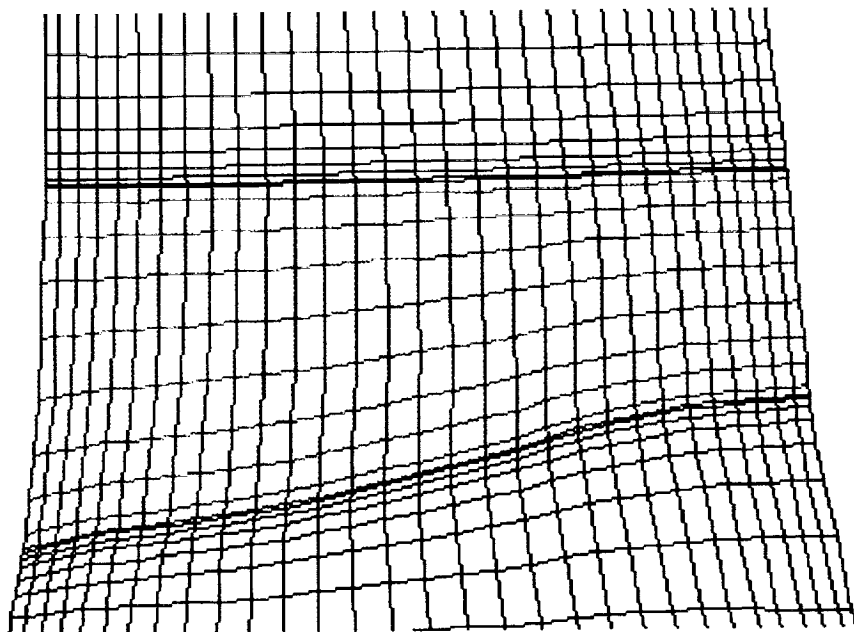


Figure 7b: Decreased Grid Number to 10

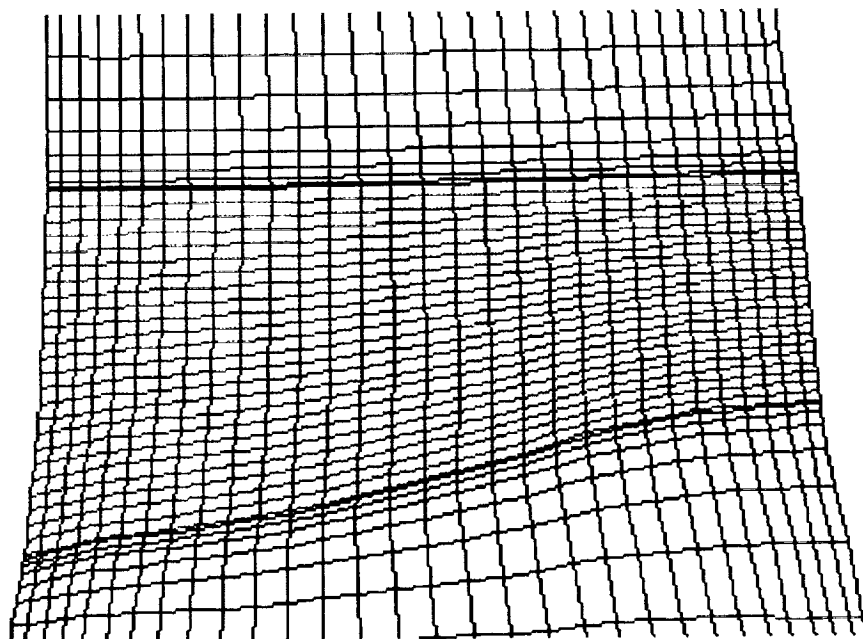


Figure 7a: Increased Grid Number to 25

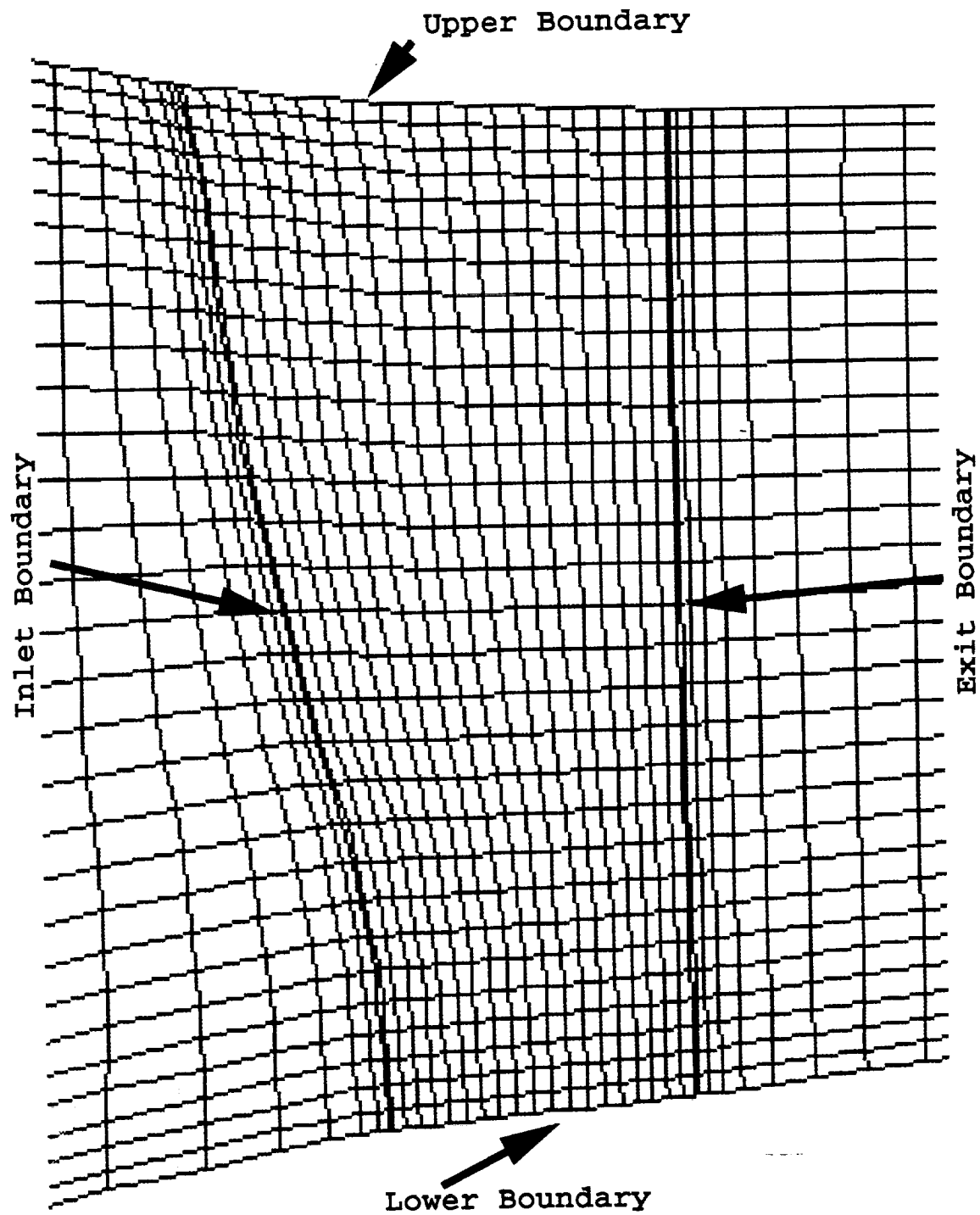


Figure 8: Row Highlighted

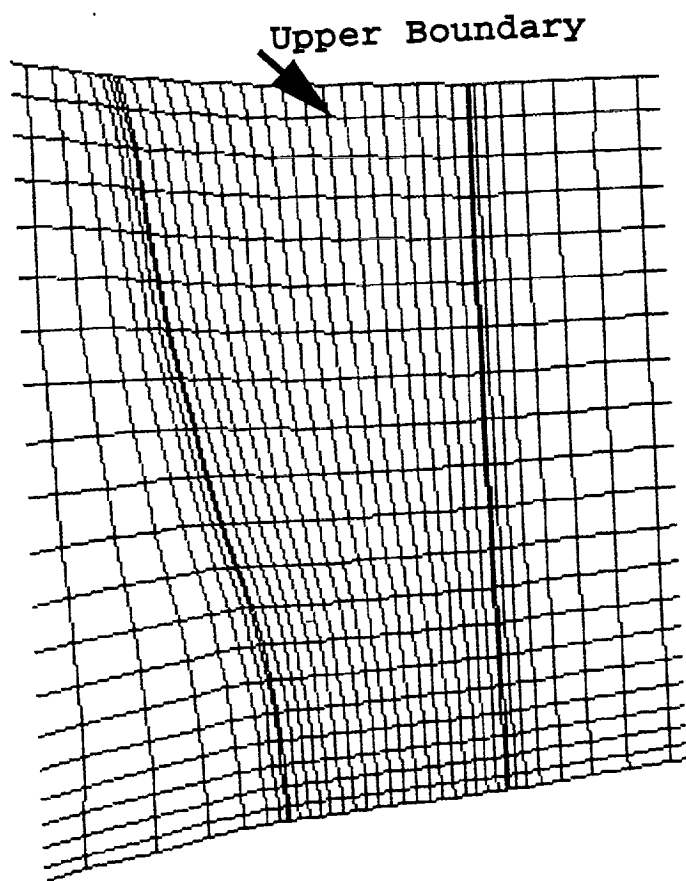


Figure 9a: Span Modification at the Top

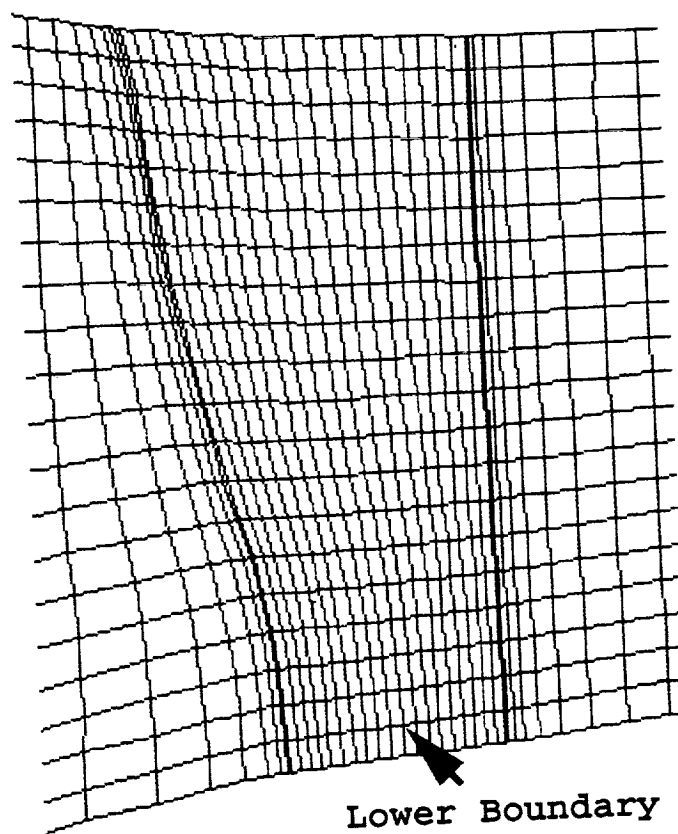


Figure 9b: Span Modification at the Bottom

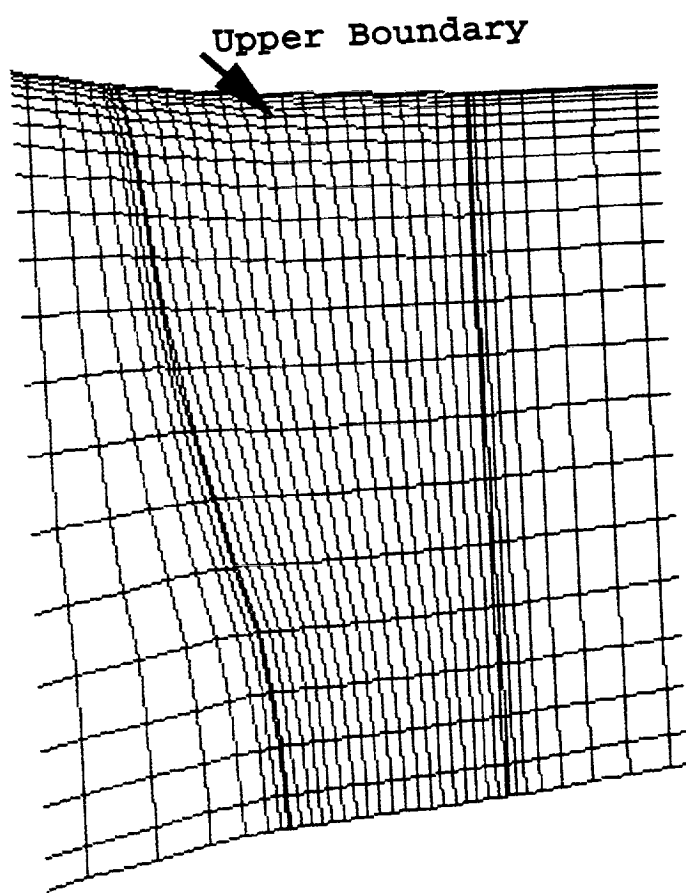


Figure 9c: Span Modification at the Top

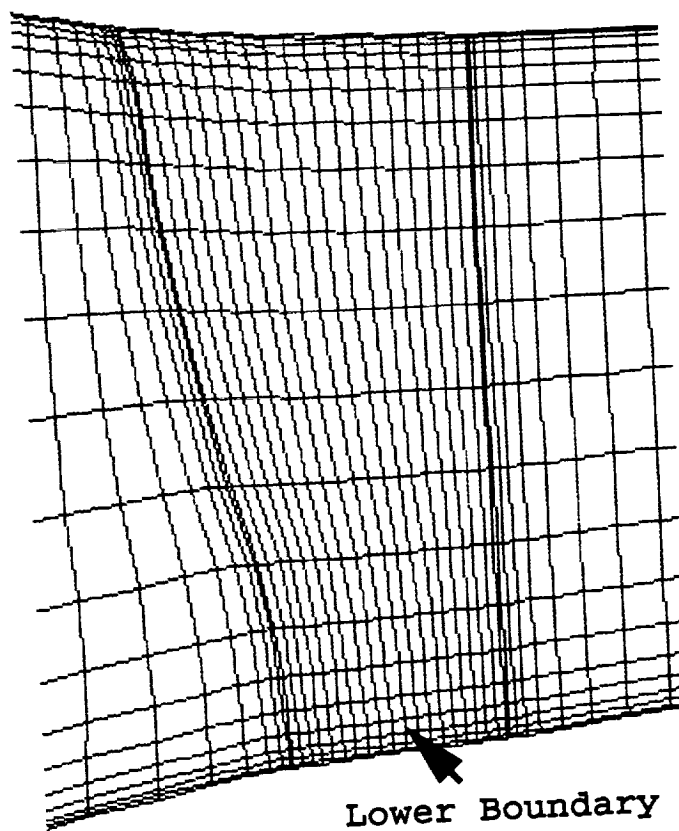


Figure 9d: Span Modification at the Bottom

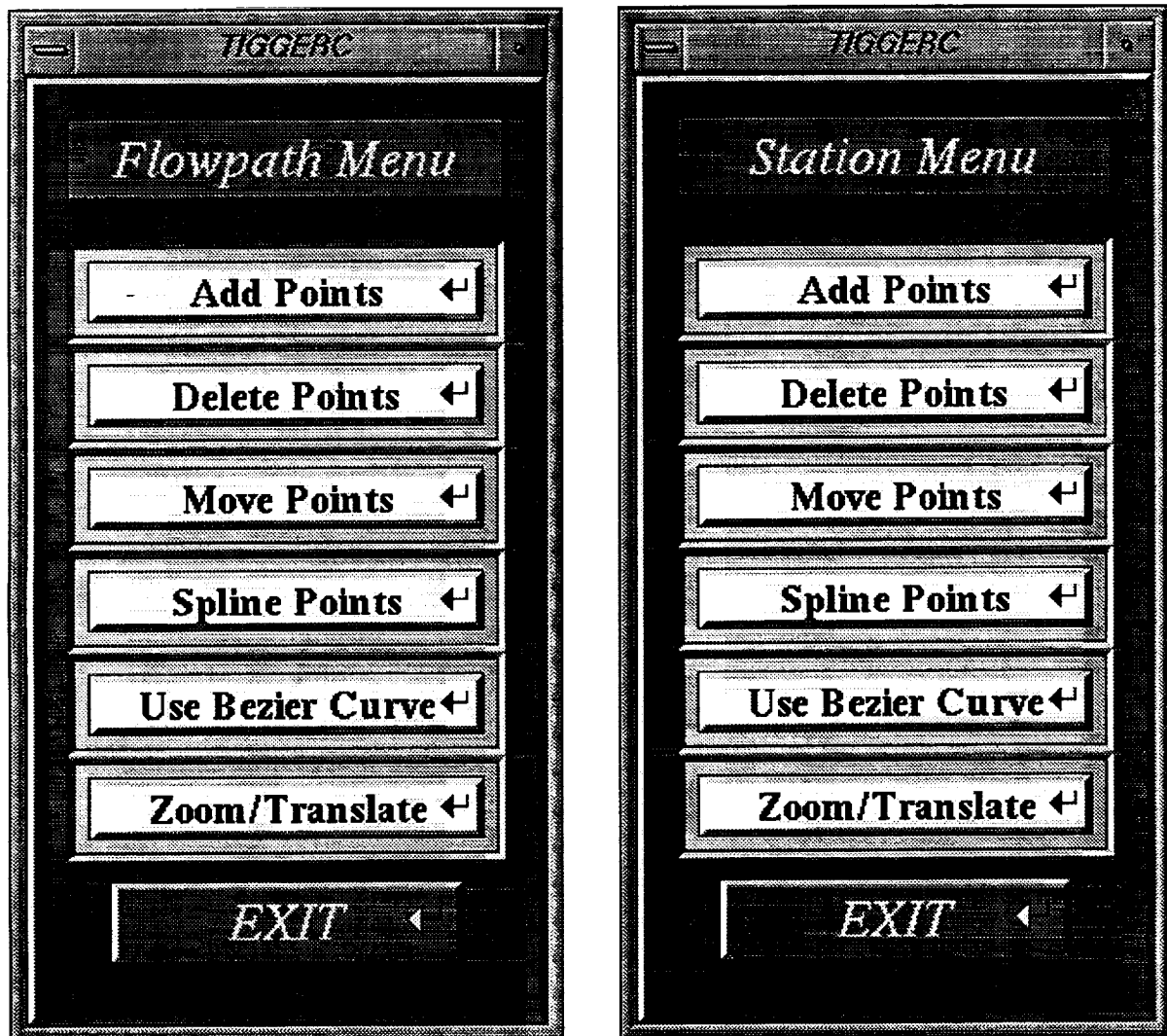


Figure 10: TIGGERC Flowpath and Station Menus

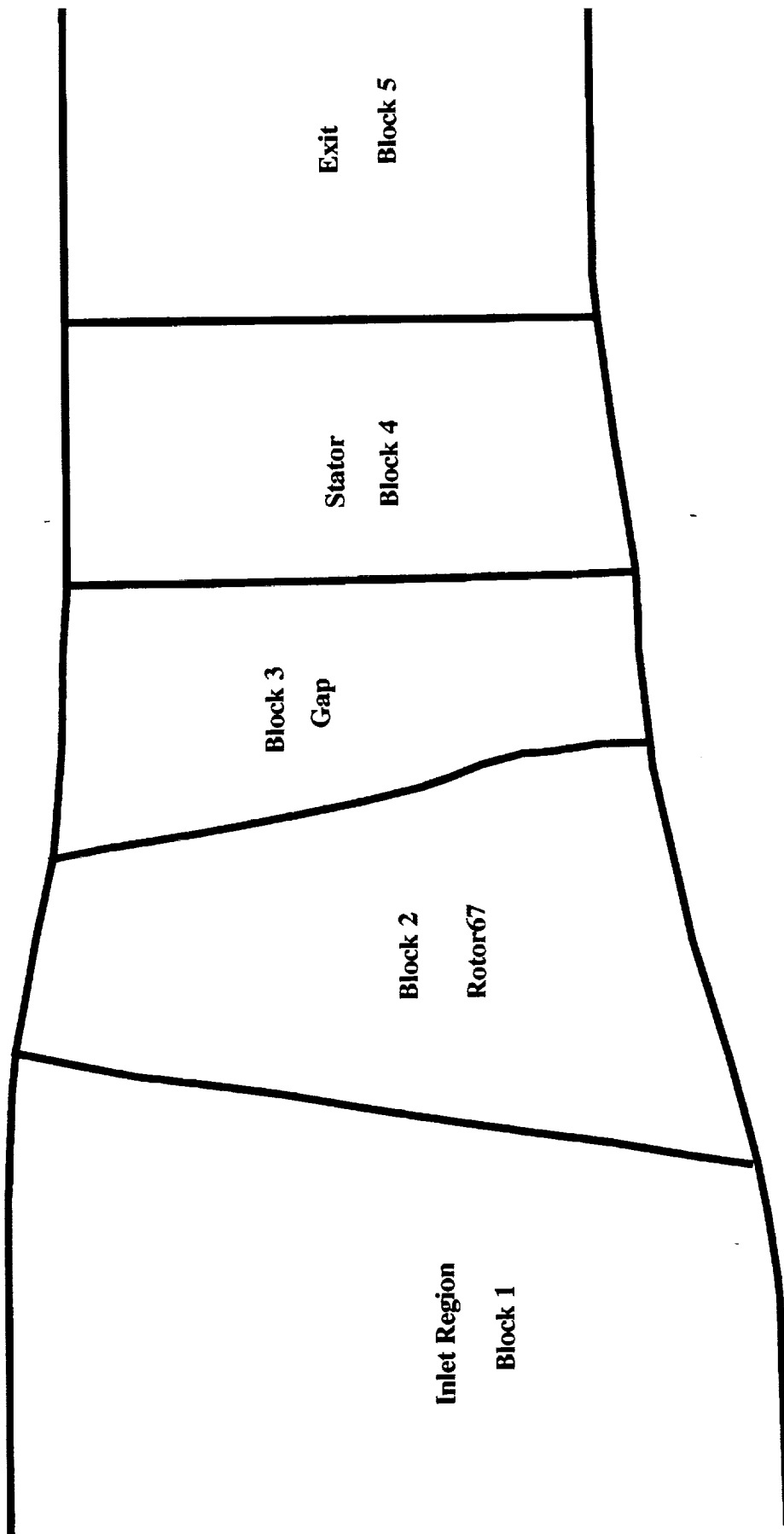


Figure 11: Rotor67 Meridional Flowpath and Blocks

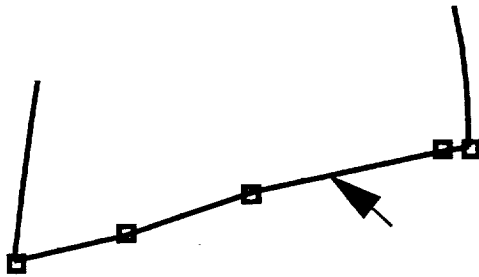


Figure 12a: Mouse Pointed at the Hub of Block2

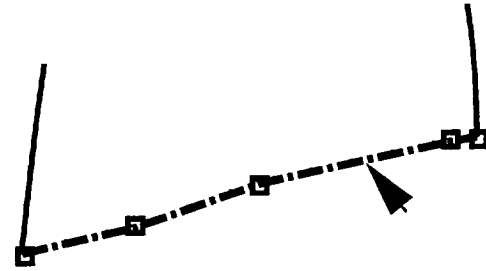


Figure 12b: Hub Highlighted after Mouse Select

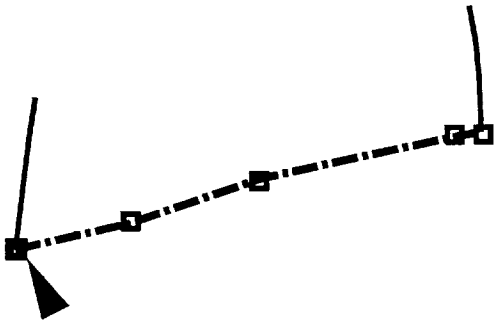


Figure 12c: Selecting the Begin Point

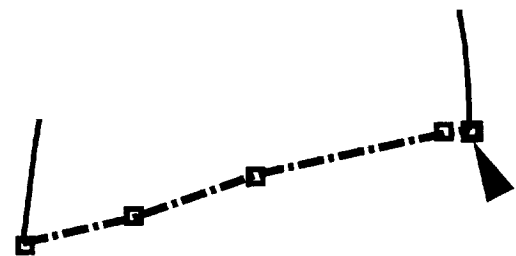


Figure 12d: Selecting the End Point

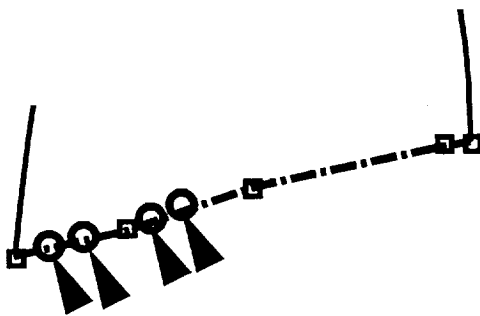


Figure 12e: Adding the Points

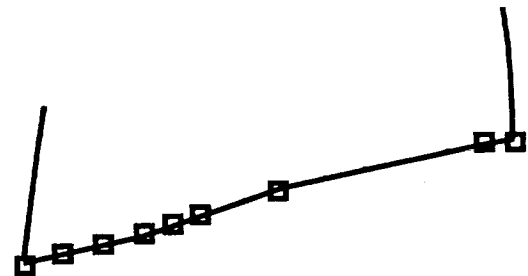


Figure 12f: New Boundary Defined

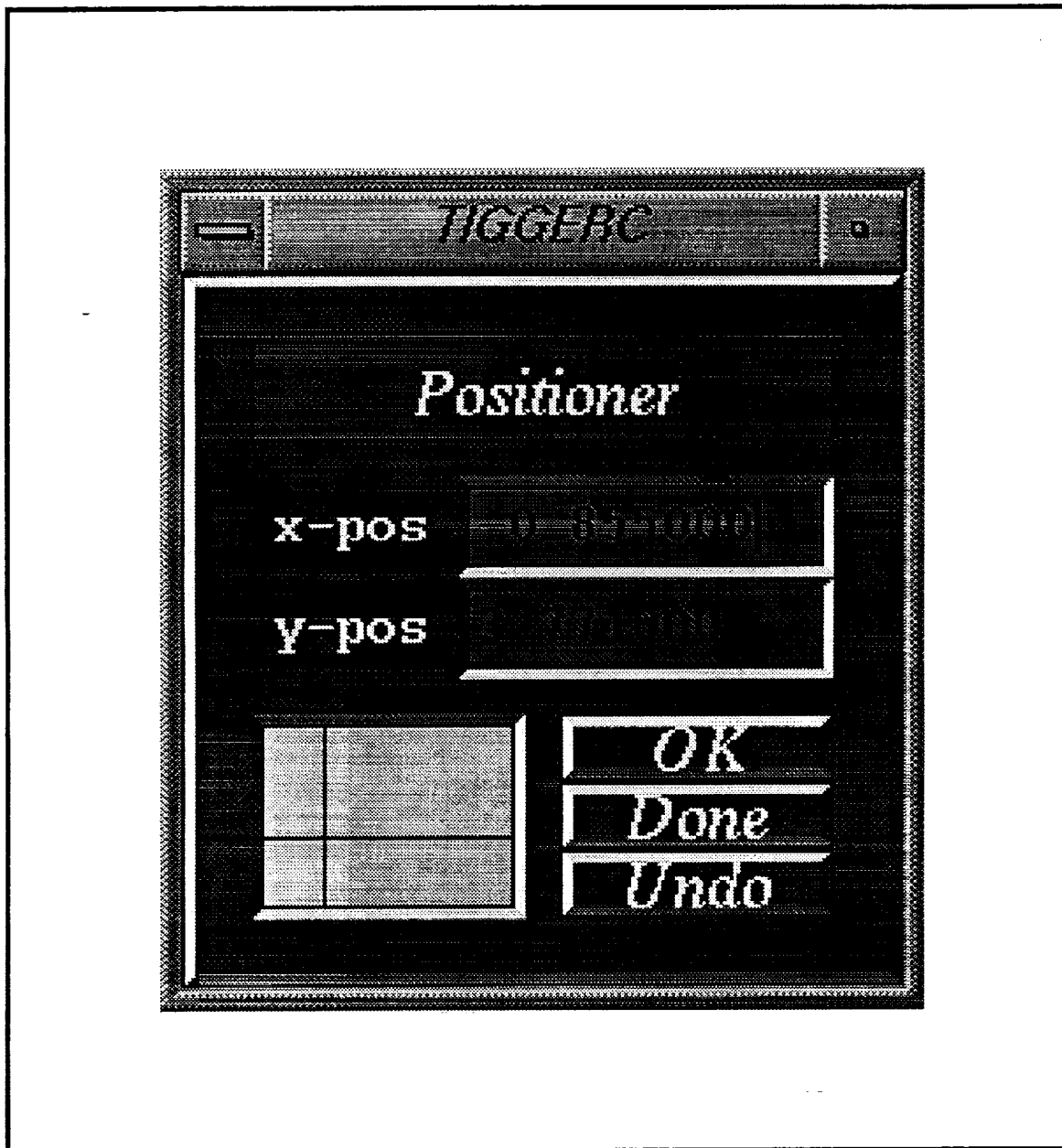


Figure 13: Point Positioner for TIGGERC

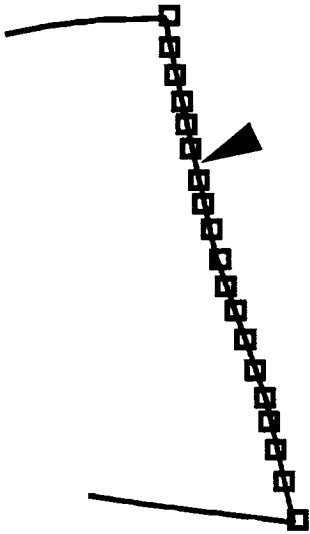


Figure 14a: Mouse Pointed at the Hub of Block 2

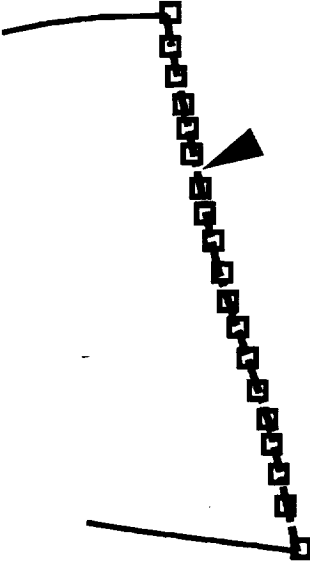


Figure 14b: Hub Highlighted when Selected

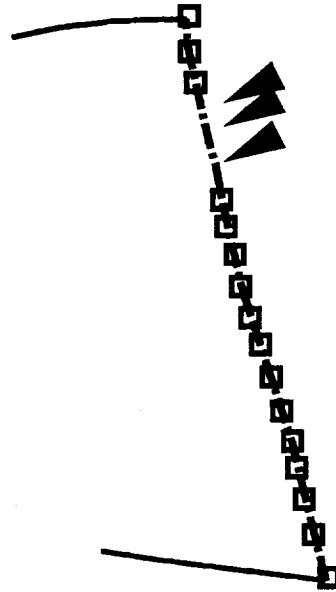


Figure 14c: Points Deleted

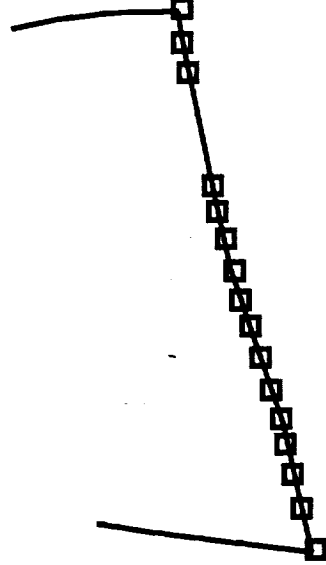


Figure 14d: Finished Deletion of Points

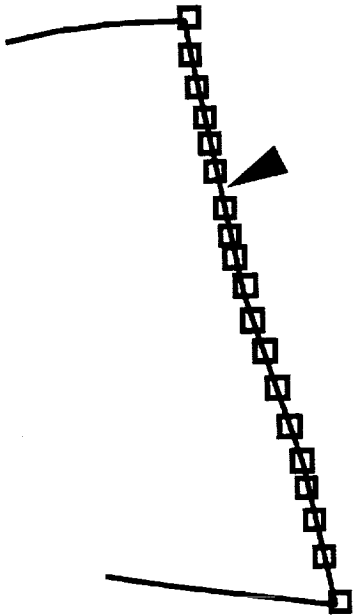


Figure 15a: Mouse Pointed at the Hub of Block 2

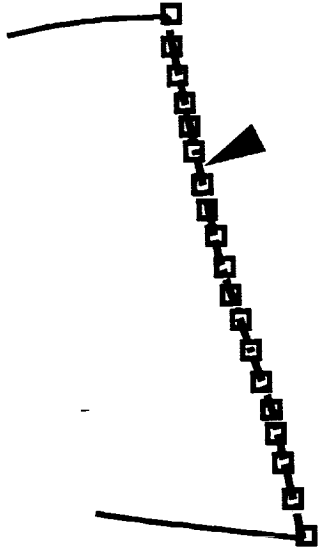


Figure 15b: Hub Highlighted when Selected

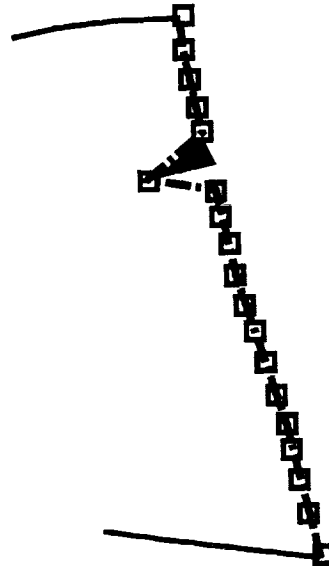


Figure 15c: Point Moved by the Mouse

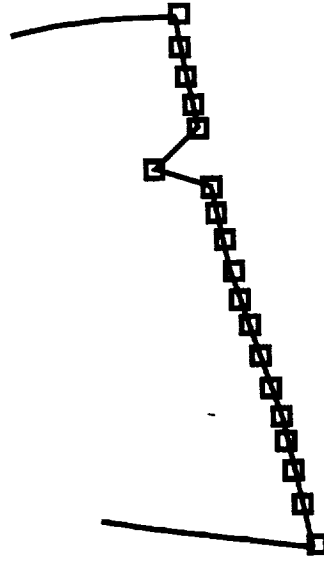


Figure 15d: Finished Moving the Points

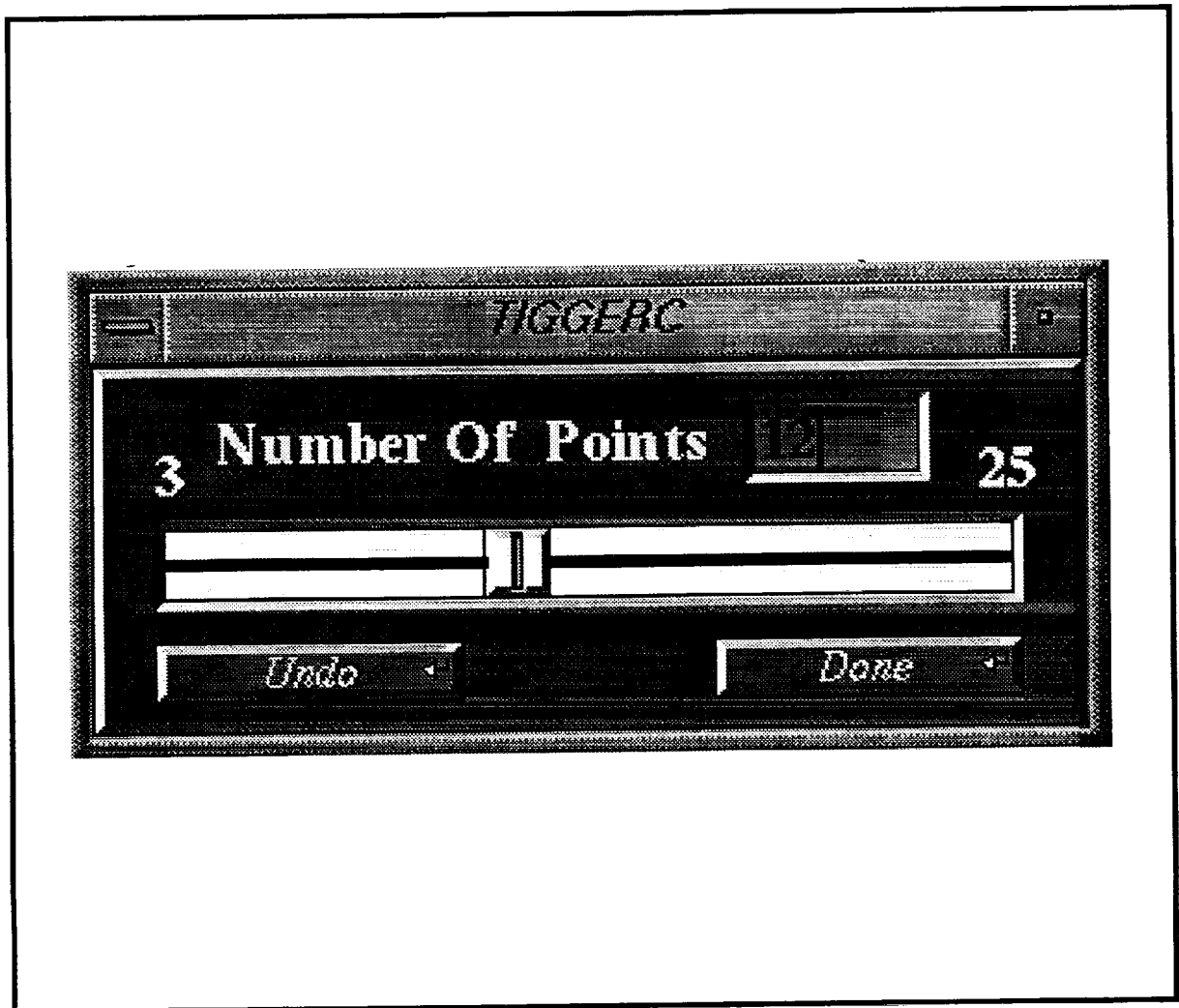


Figure 16: Slider for Splining and Bezier Functions

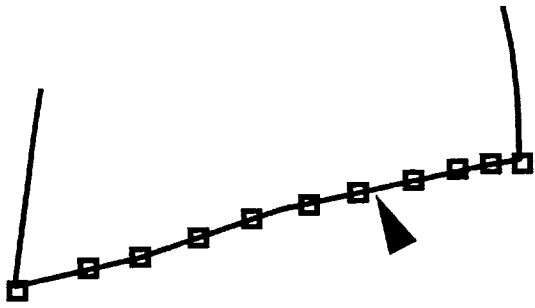


Figure 17a: Mouse Selecting Hub Contour

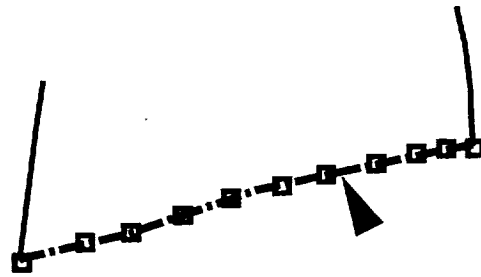


Figure 17b: Highlighted Hub

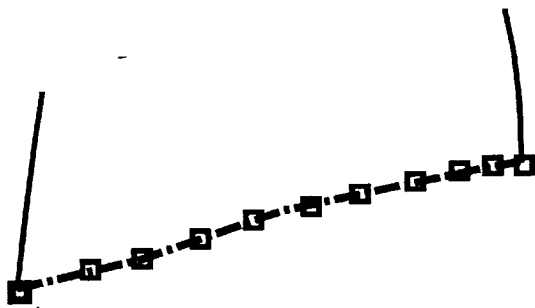


Figure 17c: Selecting the Beginning of the Spline

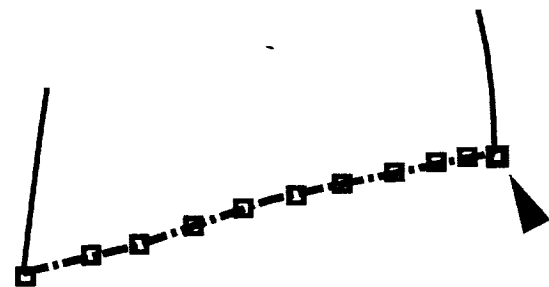


Figure 17d: Selecting the End of the Spline

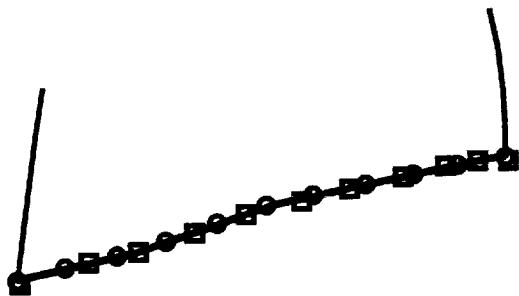


Figure 17e: New Splined Points over the Old

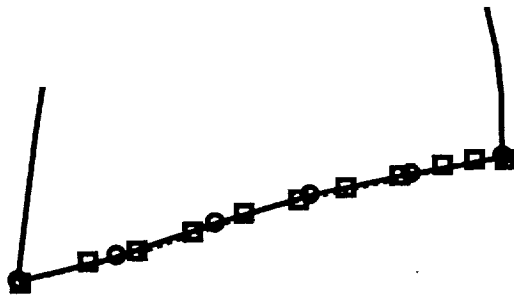


Figure 17f: Fewer Points Added by the Slider

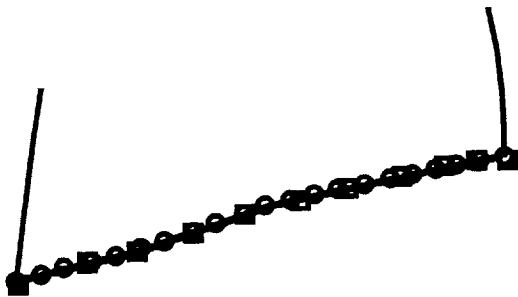


Figure 17g: More Splined Points

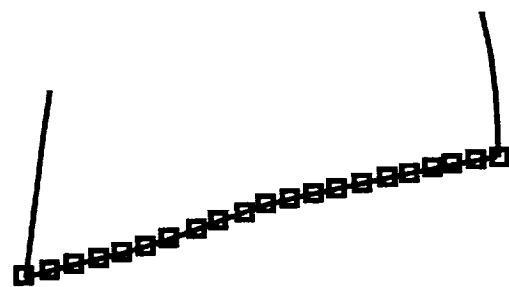


Figure 17h: Finished Spline

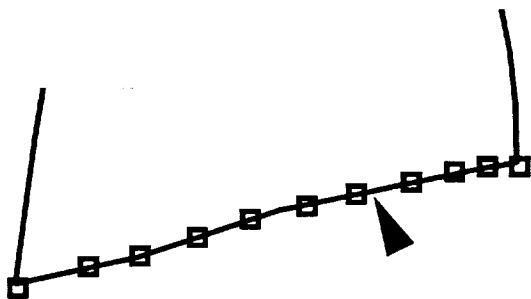


Figure 18a: Hub Flowpath Selected

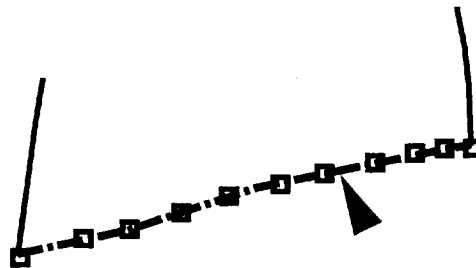


Figure 18b: Highlighted Hub

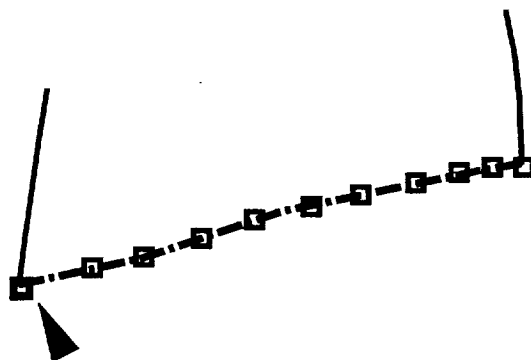


Figure 18c: Selecting the Beginning of the Bezier

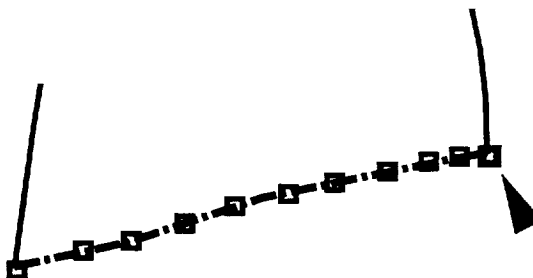


Figure 18d: Selecting the End of the Bezier

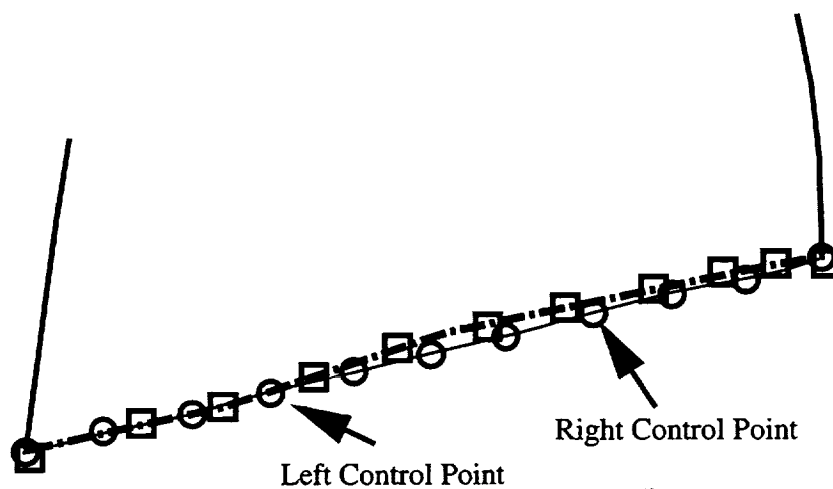


Figure 18e: Initial Bezier with Control Points

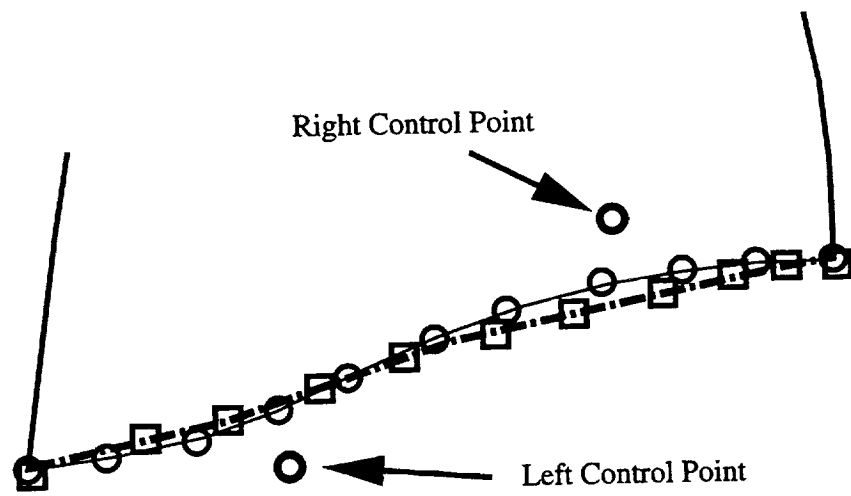


Figure 18f: Control Points Reshape Curve

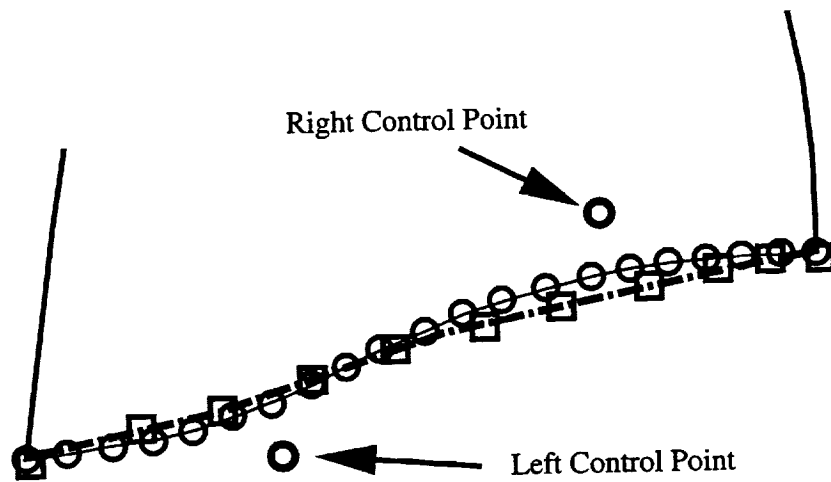


Figure 18g: Added Points to Bezier with the Slider

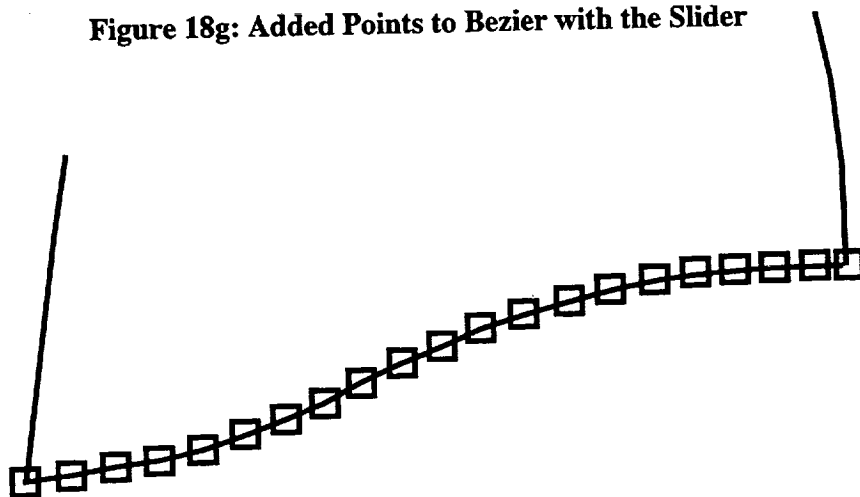


Figure 18h: New Hub Flowpath

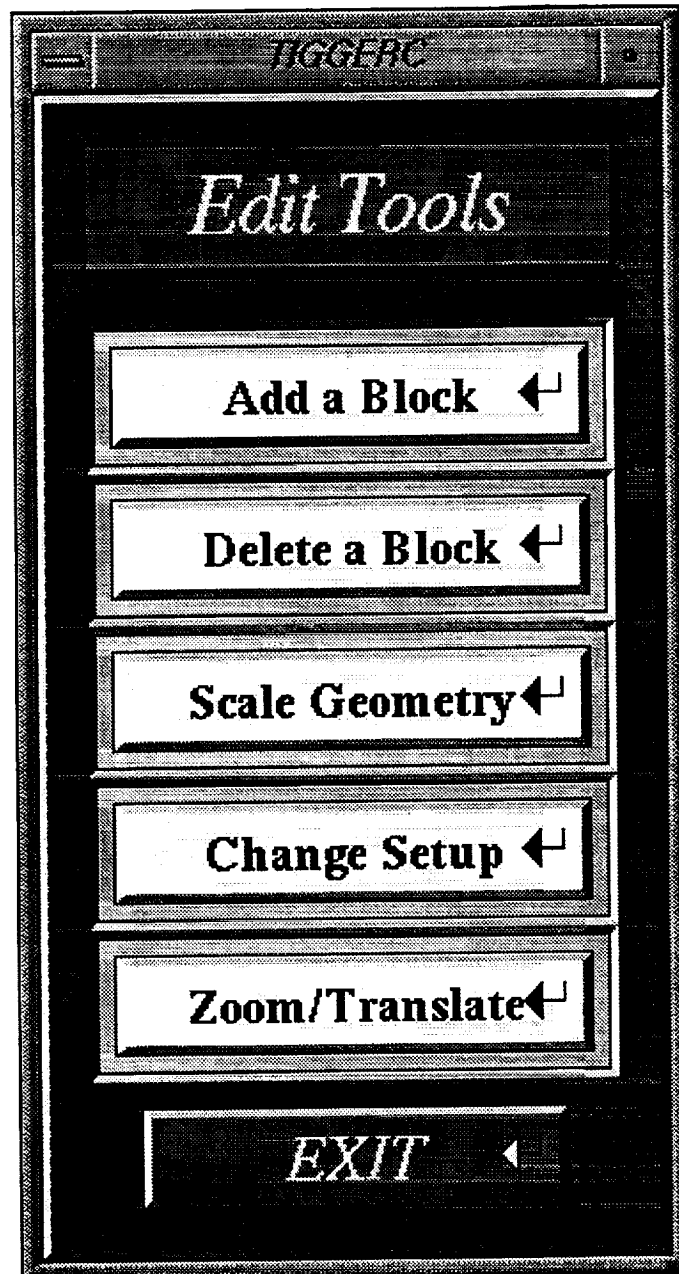


Figure 19: Edit Tools Menu

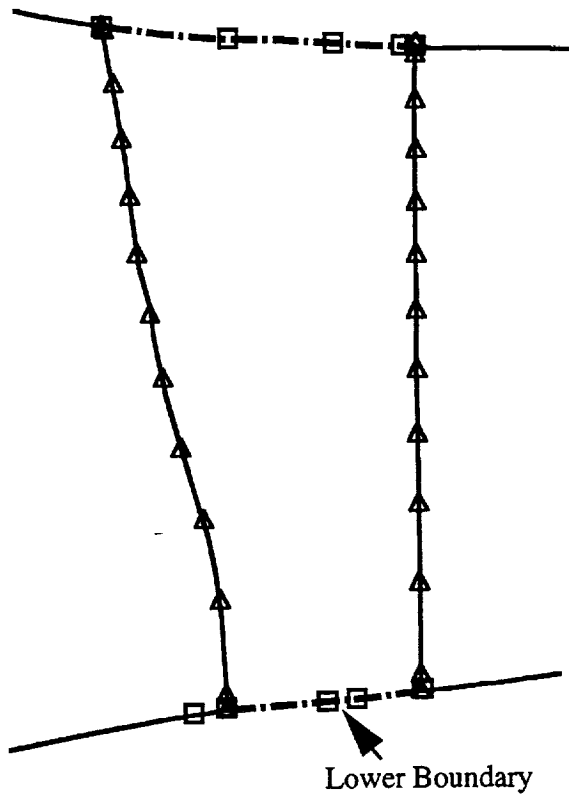


Figure 20a: Chosen Block Highlighted to add a Block

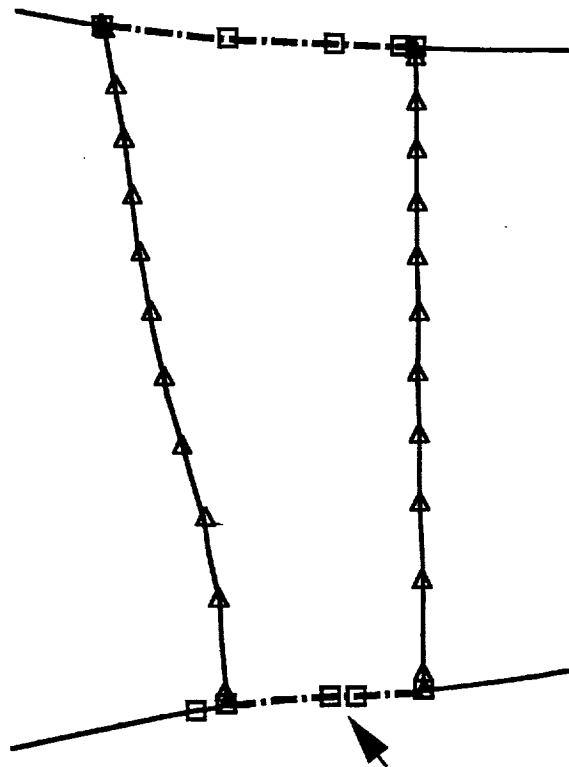


Figure 20b: Point Chosen on the Hub Flowpath

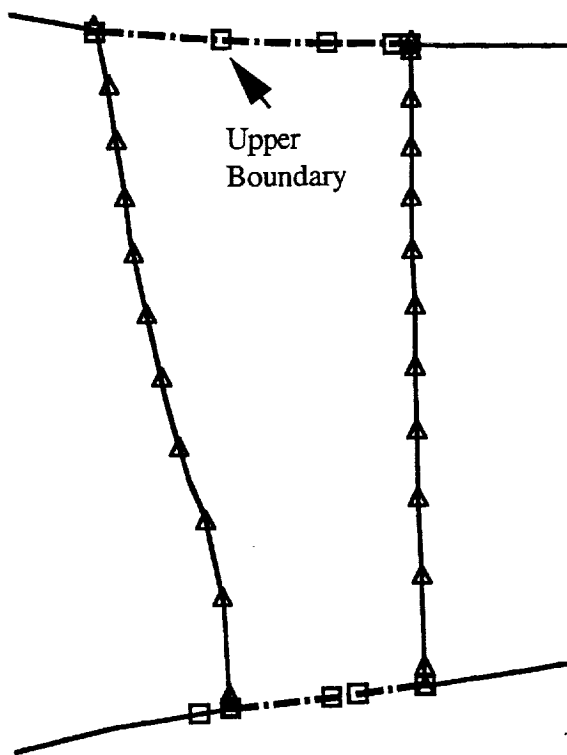


Figure 20c: Point Chosen on the Casing Flowpath

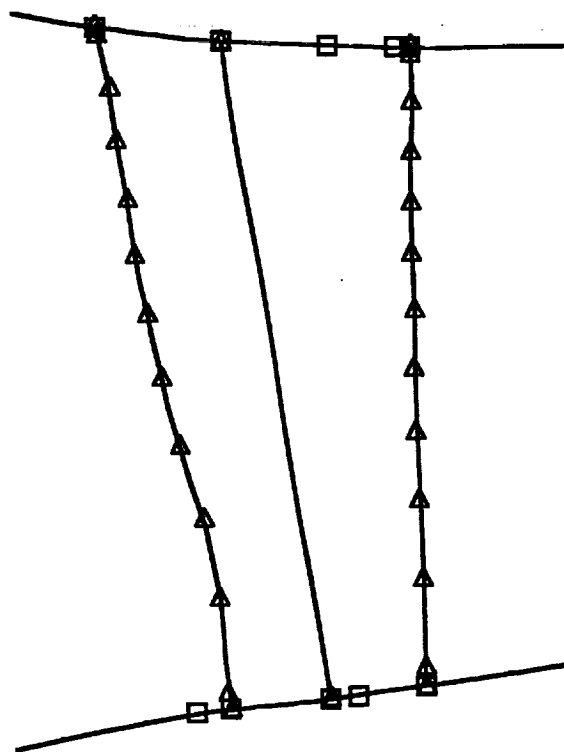


Figure 20d: New Block Added

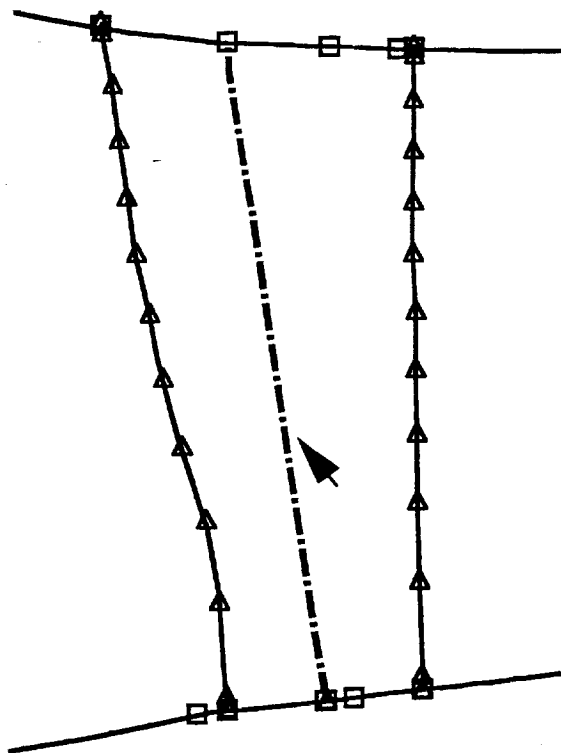


Figure 21a: Block to be Deleted Highlighted

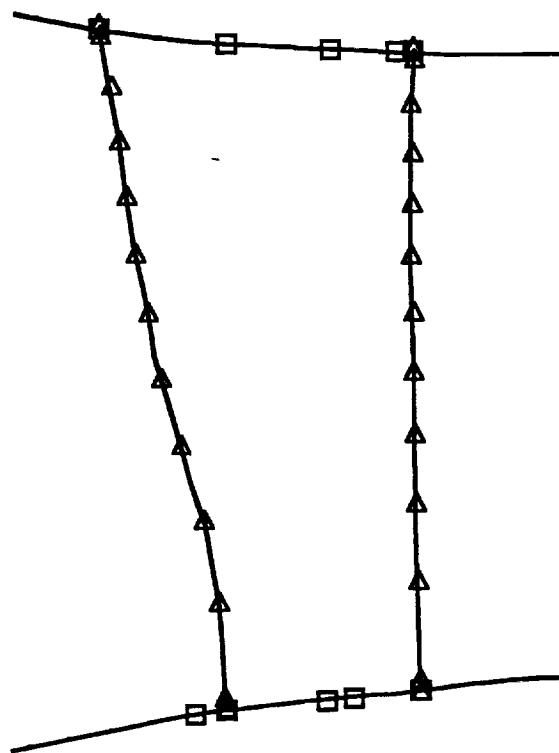


Figure 21b: Block Deleted

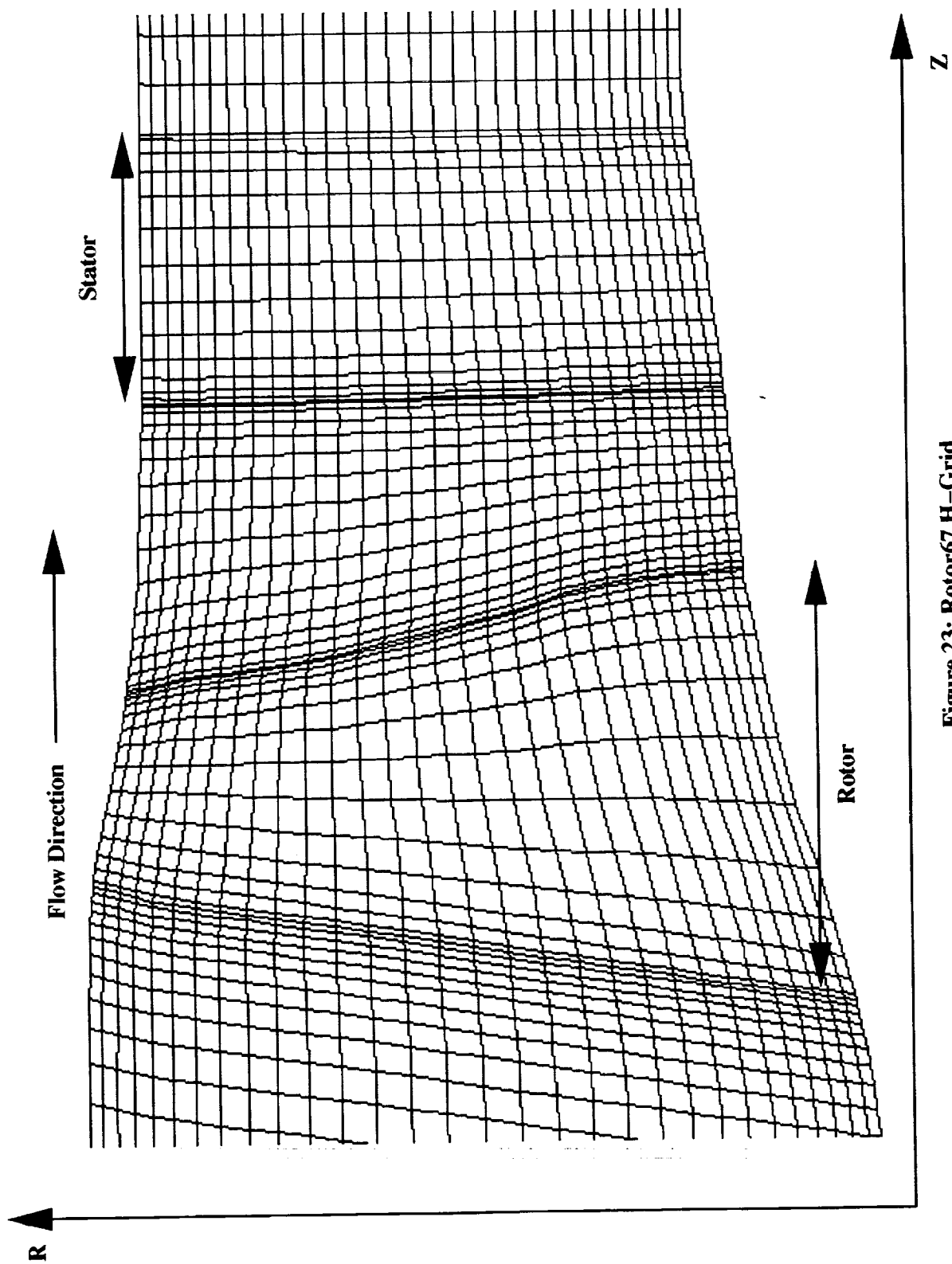


Figure 23: Rotor67 H-Grid

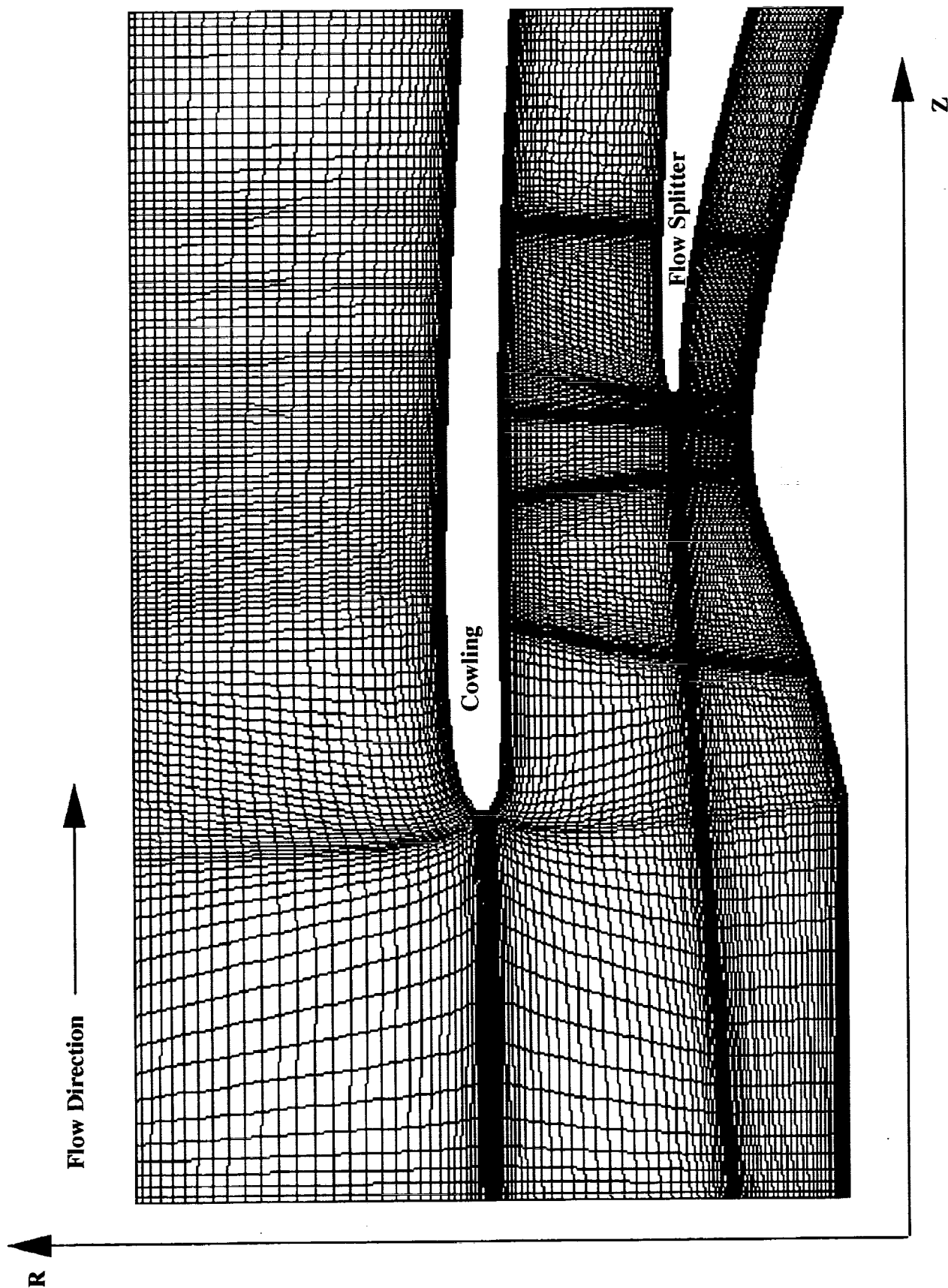


Figure 24a: Simulated ADP H-Grid

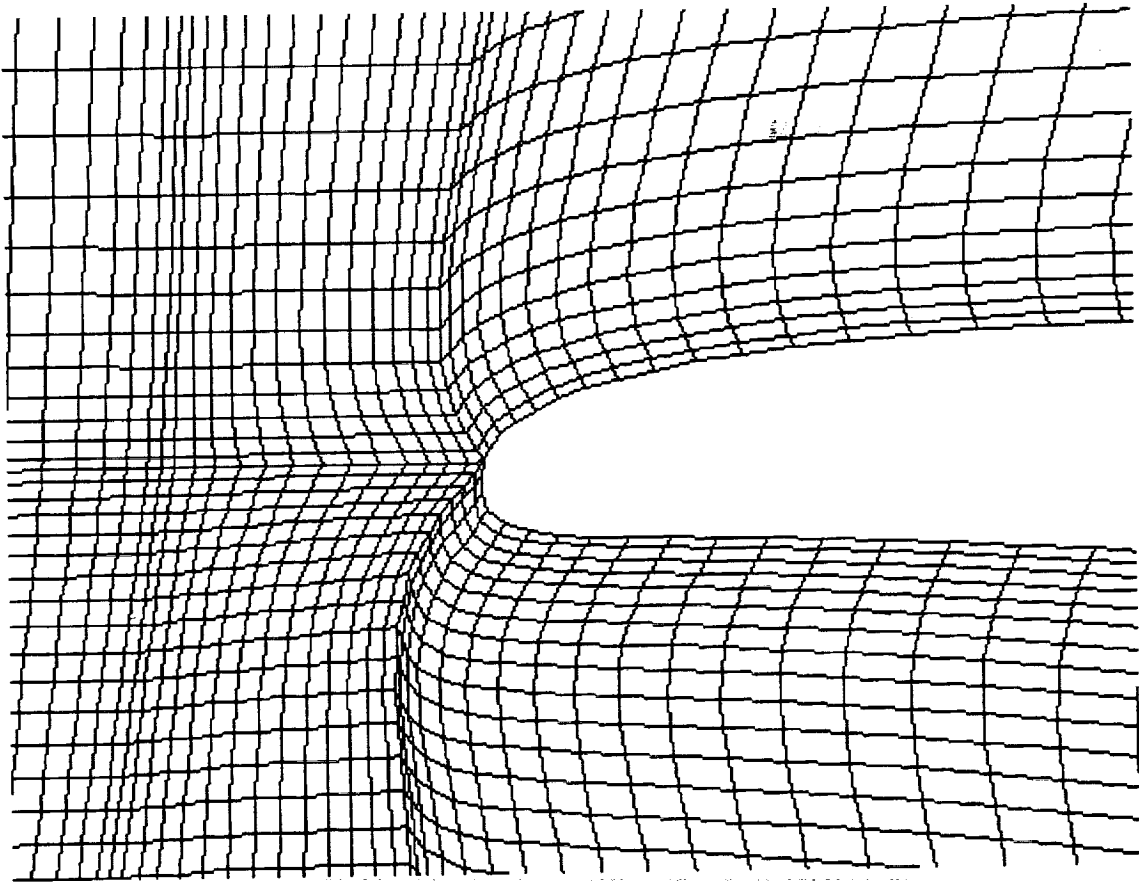


Figure 24b: Grid Distribution Around the Flow Splitter

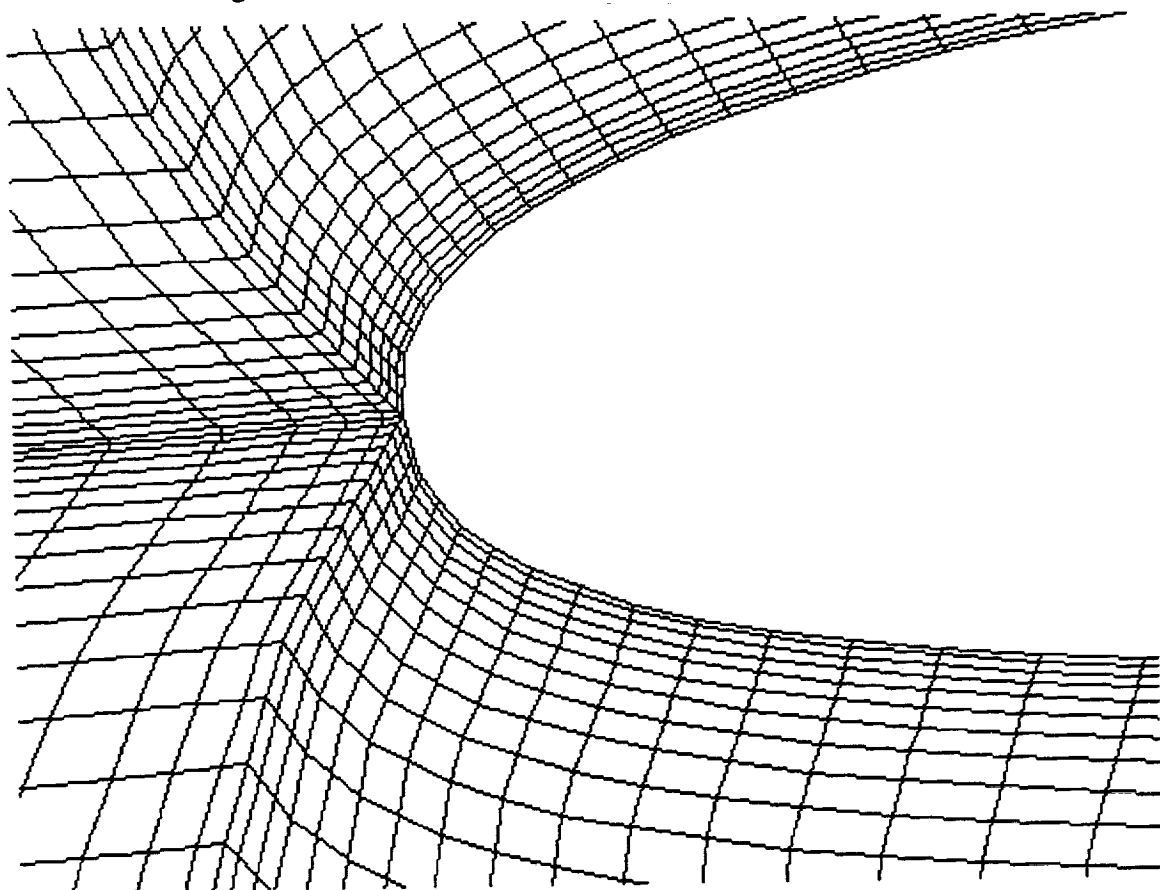


Figure 24c: Grid Distribution Around the Cowling



Figure 25: C-Grid Around NACA 64-410 Series Airfoil

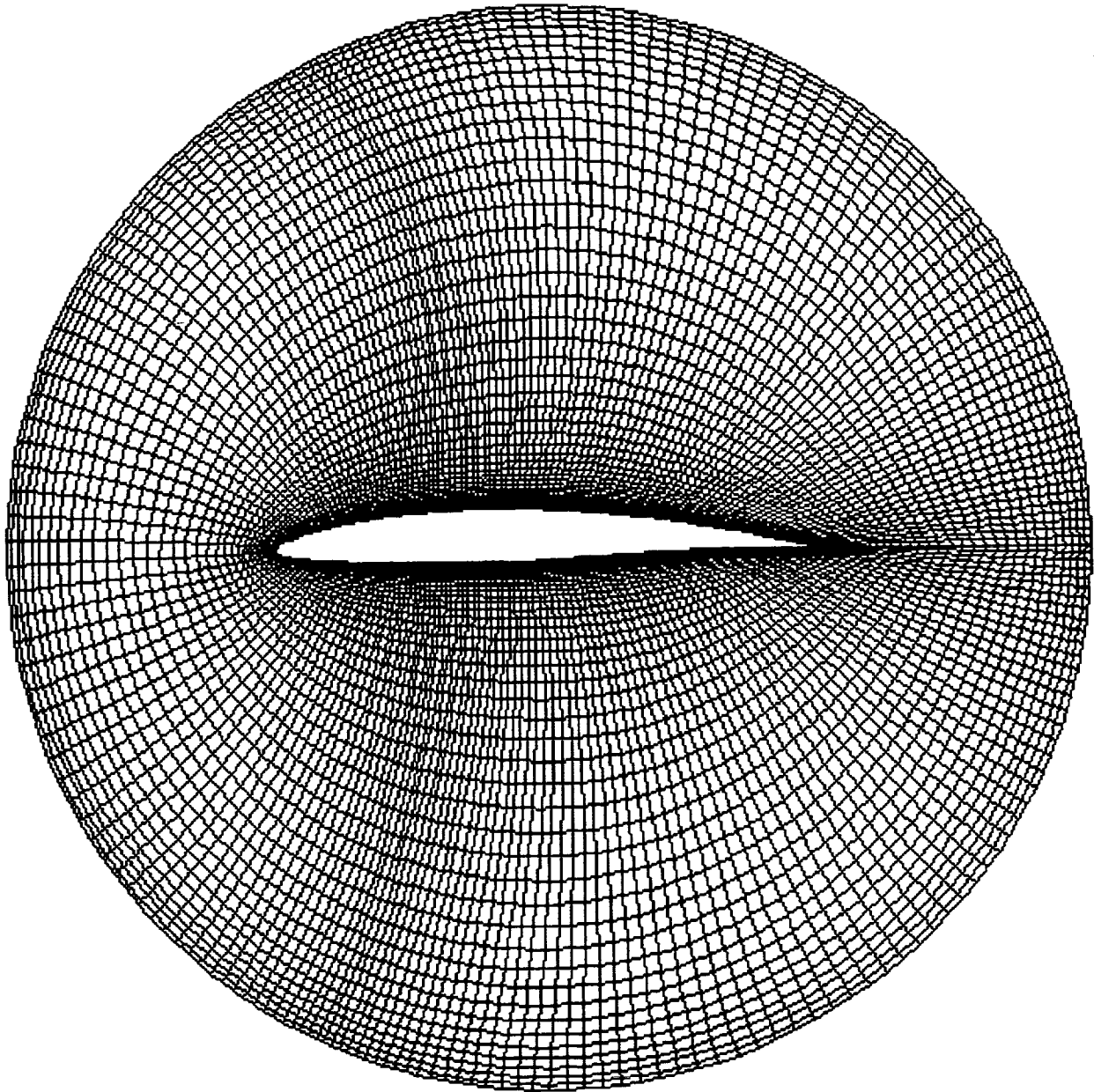


Figure 26: O-Grid Around NACA 64-410 Series Airfoil

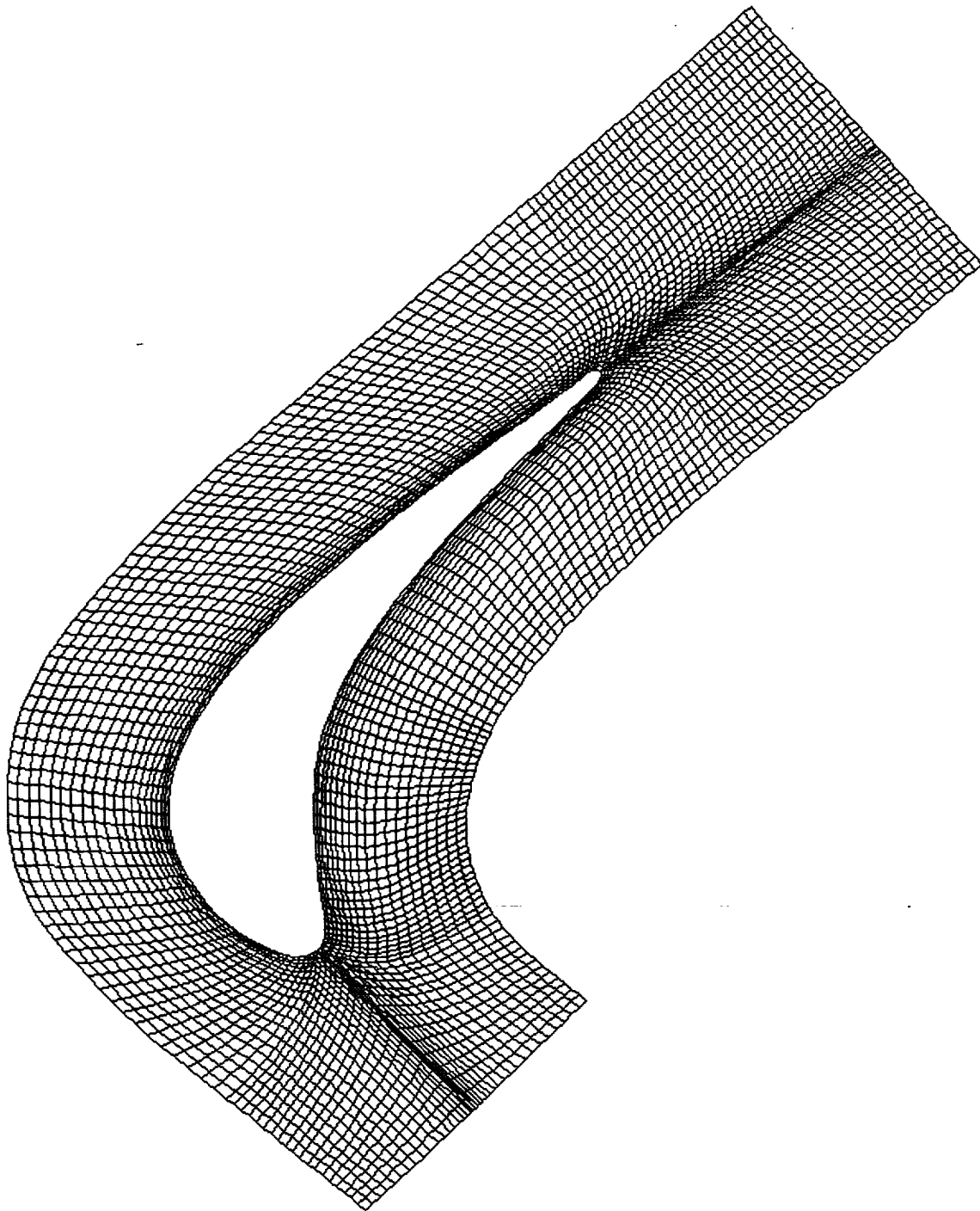


Figure 27: I-Grid Around Simulated Turbine Vane

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13. ABSTRACT (Maximum 200 words) A two-dimensional multi-block grid generator has been developed for a new design and analysis system for studying multiple blade-row turbomachinery problems. TIGGERC is a mouse driven, interactive grid generation program which can be used to modify boundary coordinates and grid packing and generates surface grids using a hyperbolic tangent or algebraic distribution of grid points on the block boundaries. The interior points of each block grid are distributed using a transfinite interpolation approach. TIGGERC can generate a blocked axisymmetric H-grid, C-grid, I-grid or O-grid for studying turbomachinery flow problems. TIGGERC was developed for operation on Silicon Graphics workstations. Detailed discussion of the grid generation methodology, menu options, operational features and sample grid geometries are presented.				
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